quarantine

DDT and OTHER INSECTICIDES and REPELLENTS

No. 8

DEVELOPED FOR THE ARMED FORCES

MISCELLANEOUS PUBLICATION No. 606
UNITED STATES DEPARTMENT OF AGRICULTURE

This publication was prepared after 3 years of intensive investigations at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine on the control of insects of importance to the armed forces. The report was originally written and issued in mimeographed form specifically for members of our armed forces and others concerned with the problems of controlling insects and insect-borne diseases affecting military personnel and civilians in occupied territories. Although it is published essentially as first prepared, the materials and methods recommended for military conditions are applicable, with only slight modifications, for both military and civilian use under peacetime conditions.

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MISCELLANEOUS PUBLICATION NO. 606

WASHINGTON, D. C. Issued August 1946

DDT and Other Insecticides and Repellents Developed for the Armed Forces [1]

Prepared by the Orlando, Fla., Laboratory of the Bureau of Entomology and Plant Quarantine

CONTENTS

[1] Interim Report No. 0–100 (NRC Insect Control Committee Report No. 100). A report to the Committee on Medical Research on work done under a transfer of funds, recommended by this Committee, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

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I. Introduction

Shortly after our entry into the war, studies were initiated by the Bureau of Entomology and Plant Quarantine for the purpose of developing control measures for certain insects [2] of importance to the armed forces. These studies were prompted by the foresight of several medical officers, as well as civilians, who were aware of the importance to the war effort of the numerous disease-bearing insects distributed throughout the world. These men included members of the staffs of the offices of the Surgeons General of the Army and the Navy, the Office of Scientific Research and Development, the Bureau of Entomology and Plant Quarantine, and other agencies. Funds for the investigations were made available by the Office of Scientific Research and Development on recommendation by the Committee on Medical Research.

Investigations on insecticides and repellents for the armed forces were begun at the Orlando, Fla., laboratory early in 1942, and a number of materials have been recommended for practical application. The various materials recommended and the methods of application suggested were first set forth in the following unpublished processed reports: Tropical Diseases Report No. 7, issued by the bureau March 7, 1944, and again in the revised edition, Tropical Diseases Report No. 19, issued May 30, 1944. The present report represents the second revision.

Several thousand materials have been tested and hundreds of formulations have been studied, but in this publication only those materials and methods that furnish information for use in practical control operations are discussed. It is intended primarily for members of the armed forces and public-health workers concerned with the control of insects and insect-borne diseases. Inasmuch as conditions in various parts of the world differ greatly and the habits and the susceptibility of insects to insecticides or repellents may vary, even among closely related forms, specific instructions cannot be given that will apply under all conditions. This publication should be considered primarily as a guide, and adaptations should be made to fit conditions as they occur in different parts of the world.

Of the various insects considered in these investigations, most emphasis has been placed on malaria-carrying and other mosquitoes and the body louse, which is the vector of typhus. Extensive research has been conducted also on mites, houseflies, head lice, crab lice, bedbugs, fleas, scab mites, cockroaches, ticks, and certain other less important insects.

Of the numerous chemicals obtained for evaluation as insecticides, DDT has been outstanding in performance. Because of its effectiveness against a number of insects of medical importance, every effort has been made to explore its possibilities and to develop formulas suitable for use in the practical control of these insects.

The properties and various uses of DDT are discussed in Parts II to VII of this publication. As a result of the development of repellents,

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[2] The term "insects" in this report is used in a broad sense to include other arthropods, such as mites and ticks.

several materials have been recommended to, and adopted by, the armed forces and their uses are discussed in Part VIII. The studies on mites (chiggers) are discussed in Part IX. Part X contains a brief summary of the toxicology of DDT, as prepared by the Food and Drug Administration, which has conducted many of the toxicological studies.

Although the recommendations discussed are based chiefly on the results of investigations at the Orlando laboratory, other available data have been included. Since Reports Nos. 7 and 19 were prepared, a large amount of valuable information has been made available by numerous observers and investigators in our armed forces, both in this country and in combat areas. In general, the results reported have been promising, and they prove the efficacy of the treatment against many species of insects and under various conditions. New and improved methods of using insecticides and repellents are also being developed by members of the armed forces and others.

Every effort has been made to encourage studies with DDT and other promising materials. Interest in the further development of control measures for certain insects of medical importance has been very great. Many other agencies have intensified their investigations in this field, and have also contributed valuable information.

In carrying out the studies herein summarized, the staff of the Orlando laboratory have had the assistance and cooperation of Army and Navy personnel, especially in the offices of the Surgeons General of the Army and the Navy, and at the Army Air Forces Center at Orlando. Other members of the Bureau of Entomology and Plant Quarantine and various agencies working on the same or related problems through grants provided by the Office of Scientific Research and Development have greatly facilitated the work at this laboratory. Excellent cooperation has also been obtained from the Rockefeller Foundation, the Arkansas State Board of Health, the Tennessee Valley Authority, and a number of commercial firms.

II. Chemistry of DDT, Other Insecticides, and Insect Repellents

History and Preparation of DDT

DDT was first synthesized in 1874, but it was not until 1939 that the Swiss firm of J. R. Geigy, S. A.,[3] reported the compound to be an effective insecticide against clothes moths, flies in stables, and certain agricultural insect pests. The Geigy company holds the patents on the use of the compound as an insecticide. The United States patent is No. 2,329,074, issued September 7, 1943, to Paul Müller. This patent also covers many other condensation products of chloral with various substances.

The compound is correctly named 1-trichloro-2,2-bis(*p*-chlorophenyl)ethane. It is also called 2, 2-bis(*p*-chlorophenyl) 1, 1, 1-trichloroethane. The term "DDT" is derived from a shorter name,

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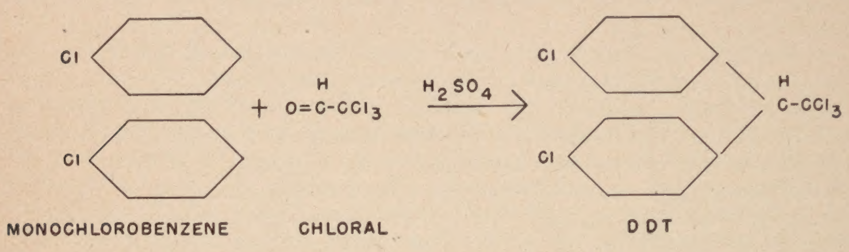
[3] Original samples and large quantities of DDT for the initial research were kindly furnished by the Geigy Co., Inc., New York City, a subsidiary of J. R. Geigy, S. A.

*d*ichloro-*d*iphenyl-*t*richloroethane, which, however, is not specific for this substance. The compound is prepared from 1 molecule of chloral or chloral hydrate and 2 molecules of monochlorobenzene in the presence of sulfuric acid (oleum is used commercially):



The DDT crystallizes from the reaction mass, and the sulfuric acid is then removed by washing.

The reaction takes place readily, but isomers in which the chlorine atoms on the benzene rings are attached in other positions and other impurities may be formed. The technical product from several commercial sources has been found to contain from 70 to 77 percent of 1-trichloro-2,2-bis(*p*-chlorophenyl)ethane, or *p,p′*-DDT. The principal impurity is 1-trichloro-2-*o*-chlorophenyl-2-*p*-chlorophenylethane, or *o,p′*-DDT, which is present to the extent of about 15 to 25 percent. If pure *p,p′*-DDT is desired, it may be obtained by recrystallization of the technical material from ethyl alcohol. Several recrystallizations are necessary to obtain a pure product.

A number of commercial firms are manufacturing DDT, and production late in 1945 reached several million pounds a month.

Properties of DDT

Pure DDT is a white crystalline substance with a melting point of 108°–109° C. The technical product melts at a lower temperature, and the present specifications call for a setting point of 88° or above. The density of the substance is about 1.6 grams per milliliter. It is stable under ordinary conditions.

DDT is nearly insoluble in water, moderately soluble in petroleum and vegetable oils, and readily soluble in many common organic solvents. Solubility values in a large number of solvents have been determined for once-recrystallized DDT (m. p. 107.5°–108° C.). The following tabulation gives the approximate solubilities in a few of the more useful solvents at 27°–30°.

Most of these solvents are inflammable, some are highly inflammable and when used as sprays, without emulsifying in water, create highly explosive concentrations in the air when used indoors or in enclosed places.

	Grams per 100 ml.
Cyclohexanone	116
Benzene	78
Isophorone	74
Trichloroethylene	64
Tetrahydronaphthalene	61
o-Dichlorobenzene	59
Acetone	58

	Grams per 100 ml.
Xylene (10-degree)	53
Carbon tetrachloride	45
Benzyl benzoate	42
Dimethyl phthalate	34
Cottonseed oil	11
Ethyl alcohol (95-percent)	approximately 2
Petroleum oils:	
Stoddard solvent	9
Kerosene, crude	8–10
Kerosene, refined, odorless	4
Fuel oil No. 1	8–11
Fuel oil No. 2	7–10
Diol 55 (high-boiling, aliphatic petroleum fraction of narrow distillation range)	7
Coal-tar light-oil distillate fractions:	
Hi-Flash Solvent	48
Heavy Solvent	58
K–327 (chiefly methylnaphthalenes)	67
Aromatic petroleum fractions:	
Velsicol AR–50 (chiefly mono- and di-methylnaphthalenes)	55
Velsicol NR–70 (chiefly tetramethylnaphthalenes)	52
S/V Culicide Oil B (chiefly methyl and polymethylnaphthalenes)	48
PD 544–B (middle fraction of S/V Culicide Oil B)	45
PD 544–C (new fraction of S/V Culicide Oil B)	44
Solvesso No. 3 (aromatic fraction, medium boiling range)	33
APS–202 (refined, high-boiling fraction of S/V Culicide Oil B)	45

Methods of Analysis

Several methods are now available for analyzing DDT. The total chlorine may be determined by combustion, followed by titration of the chloride obtained.[4] In this method a blank must be run. Total chlorine may also be determined by refluxing with sodium in isopropyl alcohol and subsequently titrating the chloride obtained (*8*).

Another analytical method consists in refluxing DDT with alcoholic potassium hydroxide.[5] One molecule of hydrochloric acid is split off, giving the corresponding ethylene compound, and the resulting chloride is titrated by the usual methods. Since results with technical DDT are higher than the actual content of *p,p'*-isomer, a blank must be used.

A method especially applicable to the analysis of technical DDT involves recrystallization from 75-percent ethyl alcohol saturated at 25° C. with pure DDT (*2*). The DDT is dissolved by refluxing, cooled to 25°, filtered by suction, washed with DDT-saturated alcohol, dried, and weighed.

A newly developed colorimetric method promises to be very useful (*5*). In this method the sample is nitrated, the tetranitro derivative formed is extracted with ether, and the ether extract is washed with alkali, dried, and evaporated. The residue is dissolved in benzene and treated with a methyl alcohol solution of sodium methylate. *p,p'*-DDT gives a blue color, *o,p'*-DDT a violet-red color. By use of a

[4] Hall, S. A., Schechter, M. S., and Fleck, E. E. CHEMICAL DETERMINATION OF DDT. U. S. Bur. Ent. and Plant Quar. ET–211, 6 pp. 1944. [Processed.]

[5] Gunther, F. A. A RAPID METHOD FOR THE QUANTITATIVE ESTIMATION OF DDT AND OF DDT SPRAY OR DUST DEPOSITS. Calif. Univ. Citrus Expt. Sta., 4 pp., addenda, 1 p. 1944. [Processed.]

suitable spectrophotometer the exact content of *p,p'*-DDT may be measured. This method is sensitive to about 10 micrograms.

Another colorimetric method involves treatment of dry DDT or a dry extract of the sample with xanthydrol-potassium hydroxide-pyridine reagent (*6*). DDT gives a red color with this reagent. This method is also sensitive to about 10 micrograms.

A colorimetric procedure has also been proposed that is based on the reaction of DDT with zinc chloride and diphenylamine to give a red color.[6] The method has been used for the determination of DDT in smokes, but is not applicable to DDT in oil clouds.

Insecticidal Preparations of DDT

SOLUTIONS

In most large-scale applications against the insects affecting man and animals solutions of DDT in petroleum oils, such as kerosene and fuel oils, will be used. Recommendations for DDT solutions in this report are on a weight-per-volume basis unless otherwise noted. A 5-percent solution on this basis means that each 100 ml. of solution contains 5 gm. of DDT.[7] Concentrations higher than 5 percent should not ordinarily be used in straight petroleum oils, as allowance must be made for reduced solubility at lower temperatures. This solution would be prepared by dissolving about 42 pounds of DDT in sufficient oil to make 100 gallons of solution, or about 43¼ pounds in 100 gallons of oil.

DDT is only slowly soluble (especially if lumpy) in petroleum oils. In preparing a drum of solution, it is suggested that the DDT be placed in a cloth bag and lumps broken up with a hammer or passed through a coarse screen. Solution will be facilitated if a sludge of the screened DDT and a small amount of the oil (say 20 pounds of DDT in 8 to 10 gallons of oil) is made first and most of the remaining lumps are broken up. This sludge is poured into the drum, rinsed in with oil, and the necessary amount of oil added. The drum is closed and, if possible, rolled in the sun occasionally during the day. The next day the contents should be examined for undissolved lumps by probing around the bottom of the drum with a long stick. If an open-top drum is available, the mixture should be stirred until all the DDT is in solution. Finely ground DDT will dissolve in a few hours, with stirring, at summer temperatures (about 90° F.). If mechanical agitating or stirring equipment is available, it may be used to advantage. For example, the Chemical Warfare Service M-4 decontamination outfit (400 gallons capacity) has been used for this purpose.

If an auxiliary solvent, such as cyclohexanone, *o*-dichlorobenzene, tetrahydronaphthalene, xylene, or one of the various coal-tar or aromatic petroleum fractions, is available, the DDT may be dissolved in it first and then added to the petroleum oil. This will reduce the

[6] JONES, W. L. COLORIMETRIC ESTIMATION OF DDT IN SMOKES. Unpublished report from Australia Munitions Supply Laboratory.

[7] If the solvent has a density of 0.82 gm. per milliliter (approximate average for kerosene and fuel oils) and it is assumed that volumes are additive on dissolving, 5 gm. of DDT per 100 ml. of solution would be equivalent to 5.16 gm. per 100 ml. of solvent, 5.92 gm. per 100 gm. of solution, or 6.29 gm. per 100 gm. of solvent.

time required for preparation of the solution. Solutions containing more than 5 percent of DDT may be obtained by adding suitable amounts of any of these solvents. For example, to obtain a 10-percent solution of DDT in a petroleum oil, it is advisable to use 10 parts of cyclohexanone to 90 parts of petroleum oil, or 20 parts of most other auxiliary solvents to 80 parts of oil. To obtain a 5-percent solution in purified kerosene, it is also necessary to add a good DDT solvent.

The choice of solvent depends on the method of application and the insecticidal use of the solution. If a comparatively light solvent is required, such materials as xylene, cyclohexanone, Hi-Flash Solvent, Solvesso No. 3, and *o*-dichlorobenzene may be used. If a moderately volatile solvent is desired, tetrahydronaphthalene, Heavy Solvent, PD 544–C, Velsicol AR–50, or K–327 may be used. These are named in approximate order of decreasing volatility. If still higher boiling solvents are required, such materials as S/V Culicide Oil, Velsicol NR–70, and APS–202 may be used. Many other similar coal-tar and aromatic petroleum fractions are available, and may be found useful for this purpose. Solvents for emulsions are discussed in the next section.

EMULSIONS

Emulsions of DDT, in which a solution of DDT in a water-immiscible solvent is emulsified with water by means of an emulsifying agent, have particularly wide application in controlling insects affecting the armed forces. Emulsions can be made to accomplish all that solutions will do, and they save shipment of large volumes of petroleum oil to be used as a solvent. The following are some of the requirements that must be met by an emulsion concentrate (the mixture before addition of water) for use by the armed forces:

1. It should mix with water readily to form a satisfactory emulsion without requiring special mixing equipment.
2. It should form a satisfactory emulsion not only in soft water, but in hard and sea water.
3. The emulsion formed should be reasonably stable at concentrations used in spraying (0.1 to 10 percent DDT), but extreme stability is not necessary.
4. It should be adaptable to as many uses as possible, but especially as a residual adulticide spray and as a mosquito larvicide.
5. It should contain as high a concentration of DDT as is consistent with other requirements.
6. There should be no separation of DDT from the concentrate on storage at low temperatures.
7. The flash point should be high enough for safety in shipping.

For certain specific uses and under favorable conditions more economical preparations than those discussed below can be made. For military use under a wide variety of conditions and against a number of different insects, requirements must be much more rigid.

A large number of emulsifiers and combinations of emulsifiers have been tested with many water-immiscible solvents. Originally a formula containing 20 percent of DDT, 20 percent of Triton X–100 (an aralkyl polyether alcohol, formerly called Triton NE–100 percent), and 60 percent of xylene (all by weight) was recommended. This formed a very stable emulsion in water. More recently, however, it was found that the proportion of emulsifier could be reduced without interfering with the usefulness of the concentrate. The later formula

is 25 percent DDT, 10 percent Triton X–100, and 65 percent xylene. This emulsion concentrate has been used successfully in a large number of laboratory and large-scale field tests as a mosquito larvicide, a residual spray for adult insects, and in louseproofing underwear. It has also been used in mosquito-control operations.

Emulsions are made by adding the required amount of concentrate slowly to water with continuous stirring. To prepare a 5-percent emulsion of DDT, 1 volume of the concentrate is mixed with 4 volumes of water (the density of the concentrate is close enough to 1 gm. per milliliter to make this dilution by volume satisfactory). A 1-percent DDT emulsion made from this concentrate is cheaper than 1-percent DDT solutions in fuel oil or kerosene.

Although this concentrate has been satisfactory from the insecticidal standpoint, it does not meet requirements 6 and 7 listed above. Therefore, considerable effort has been directed toward finding more suitable solvents than xylene. It has recently been found that Hi-Flash Solvent, Solvesso No. 3, and PD 544–C may be used as principal solvents with certain proportions of either cyclohexanone or isophorone as auxiliary solvents to obtain concentrates that will meet these two requirements. Although final recommendations have not been made, 25 percent of DDT, 12 percent of Triton X–100, about 15 percent of either of the auxiliary solvents just mentioned, and about 48 percent of one of the principal solvents given above appears satisfactory. Other aromatic petroleum fractions (i. e., low-boiling Velsicol cuts) and coal-tar fractions may also be found useful as principal solvents. New lots of PD 544–C are sufficiently good solvents for DDT to be used without auxiliary solvent, provided the concentrate is not subjected to a very low temperature.

These newer concentrates give emulsions that are equally as effective as the xylene emulsion when used as residual sprays for adult insects, as airplane sprays against adult mosquitoes, and as mosquito larvicides. Although they would be effective in louseproofing underwear, they would not be satisfactory for this purpose because the solvents are less volatile than xylene and a certain amount would remain in the clothing.

DDT-emulsion concentrates may be used to prepare quick-breaking emulsions for use as mosquito larvicides. Such emulsions can be made by adding 1 part of the emulsion concentrate to 3 or 4 parts of fuel oil and emulsifying this with water. The concentrates may also be used to prepare straight solutions of DDT in oil. The presence of the emulsifier will aid spreading of the oil in mosquito-larvicide operations.

A mixture of equal quantities of Span 20 (sorbitan monolaurate, technical) and Tween 20 (sorbitan monolaurate polyoxyalkylene derivative) has been found as satisfactory as Triton X–100. Other emulsifiers that appear about equally good in preliminary tests are Duponol G (an alkyl sulfate), Igepal CA Extra High Concentrated (alkyl aryl polyglycol ether), and Emulside 820 (cocoanut fatty acids of modified polyglycols), although these do not all give such stable emulsions in sea water as does Triton X–100.

Emulsifiers not so satisfactory for this particular purpose, but which may be used under certain conditions, are Alkanol B and Alkanol SA

(sodium alkylnaphthalene sulfonates), Alkanol WXN (sodium hydrocarbon sulfonate), Aresklene 400 (sodium sulfonate of dibutylphenylphenol), Emulphor ELA (polyglycol ether ester), Tween 80 (sorbitan monooleate, polyoxyalkylene derivative), Tween 60 (sorbitan monostearate, polyoxyalkylene derivative), and Wetsit Concentrated (alkylated aromatic sulfonate).

A moderately satisfactory emulsion may be made by adding a solution of DDT in xylene or other water-immiscible solvent to a 1-percent soap solution in water, with vigorous stirring.

SUSPENSIONS

Some work has been done with colloidal or very finely divided suspensions of DDT particles in water, such as are obtained when solutions of DDT in a water-miscible solvent and a suitable wetting agent are added to water. They have been used primarily as mosquito larvicides.

A simple type of aqueous suspension consists of powdered DDT, usually mixed with talc, suspended in water in the presence of a wetting agent. A useful preparation is a mixture of the powdered DDT-talc dust with a powdered wetting agent, such as sodium lauryl sulfate (Duponol C). This makes a good suspension when shaken with water, but of course must be kept well agitated while in use. A similar suspension may be made by adding the DDT-talc dust to soapy water. Such suspensions have been used both as residual sprays and as mosquito larvicides.

A type of preparation which appears very promising is a dispersible, or wettable, DDT which is being developed by an O. S. R. D. group. It consists of 90 to 99 percent of technical DDT with small amounts of agents to prevent caking and aid dispersion. This and other dispersible DDT preparations containing 40 to 50 percent of DDT readily mix with water to give good suspensions and are particularly useful as a residual spray against adult insects. When suspensions or dispersible powders are employed as a spray, it is recommended that the DDT concentration be reduced to 2.5 percent or less, because these preparations are generally more difficult to apply with existing spray equipment.

DUSTS

Because of the low setting point of the technical product, it has been difficult to grind DDT alone. DDT can be readily ground with a diluent such as pyrophyllite or talc. At least 75 to 80 parts of diluent to 25 to 20 parts of DDT was at one time said to be necessary for satisfactory grinding. Recently, however, some manufacturers have been able to furnish dusts containing 50 percent of DDT

The undiluted technical DDT tends to cake on shipment. Promising results have been obtained by the Division of Insecticide Investigations of this bureau in the use of a conditioner with DDT to produce a material which is more free-flowing and has less tendency to cake. Until such an improved product is available, it appears advisable to prepare dusts in this country or where adequate grinding facilities are available.

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Benzene Hexachloride

A material that has recently come into prominence as an insecticide is benzene hexachloride (1, 2, 3, 4, 5, 6-hexachlorocyclohexane). Several isomers of this substance are possible, and at least four are present in the crude commercial preparation. The principal active insecticidal substance is the gamma isomer, of which the crude product contains only about 12 percent. The crude product has a pronounced musty odor and, in general, is less soluble in petroleum oils and other solvents than is DDT. The pure gamma isomer has a much less pronounced odor but is difficult to prepare.

In experiments at this laboratory benzene hexachloride has shown particular promise for the control of blowfly breeding and in area control of mites.

Chemistry of Repellents and Miticides

The four standard-issue mosquito repellents are dimethyl phthalate, Rutgers 612, Indalone, and a mixture of these three repellents. Dimethyl phthalate is also useful as a miticide. Benzyl benzoate has recently been found very promising as a miticide. The uses of these materials as repellents and miticides are discussed in Parts VIII and IX. Several thousand organic substances are being investigated for these purposes, and many of them appear promising.

Dimethyl phthalate is prepared by the esterification of phthalic anhydride with methyl alcohol. It has a specific gravity of about 1.19 and a boiling point of 282° C.

Rutgers 612 (2-ethyl-1,3-hexanediol) may be made from 2 molecules of butyraldehyde by condensation and reduction to the diglycol. It has a specific gravity of 0.94 and a boiling point of 244° C.

Indalone (*n*-butyl mesityl oxide oxalate) is made from mesityl oxide and butyl oxalate by a Claisen condensation using sodium butylate as a condensing agent. In the commercial product a large proportion is said to exist in a ring form (2,2-dimethyl-3-hydro-6-carbobutoxy-4-pyrone). It has a specific gravity of 1.06 and a boiling range of 110°-115° C. at 1 mm. pressure. It is unstable in water and in alkaline media.

Benzyl benzoate is usually prepared from 2 molecules of benzaldehyde by the catalytic action of sodium benzylate. It has a melting point of 21° C., a boiling point of 324°, and a specific gravity of 1.11.

For the impregnation of clothing, and particularly for use as a miticide, it is desirable to use an aqueous emulsion. The most convenient form is a concentrate containing the repellent and emulsifier, which may be emulsified with water. Many emulsifiers have been tested for this purpose. A satisfactory proportion appears to be 90 percent of repellent and 10 percent of emulsifier. This concentrate is agitated vigorously with two to three times its volume of water until a creamy emulsion is obtained, and then further diluted with water, using moderate agitation, to the desired repellent concentration (usually 5 percent). When used in this way, the following emulsifiers produce satisfactory emulsions of dimethyl phthalate and benzyl benzoate in fresh water: Tween 80 (sorbitan monooleate polyoxyalkylene

derivative), Tween 60 (sorbitan monostearate polyoxyalkylene derivative), polymerized glycol monolaurate, polymerized glycol monostearate, or polymerized glycol monooleate, Stearate 61–C–2280 (a polyalkylene glycol stearate), and Triton X–100.

If sea water must be used to prepare the emulsion, the choice of emulsifier is restricted. Of the foregoing, only the polymerized glycol products (monolaurate, monostearate, and monooleate) and Stearate 61–C–2280 gave good emulsions of dimethyl phthalate and benzyl benzoate in sea water. A 50:50 mixture of Span 60 (sorbitan monostearate) and Tween 60 also gave a good emulsion in this water. Emulsions in sea water with Tween 80 and Tween 60, although not so good as the foregoing, would be considered satisfactory for use.

Military-Issue Items

DDT, repellents, and miticides are supplied to the armed services in the forms listed below. Similar DDT preparations can also be obtained from industrial firms supplying DDT insecticides.

1. Technical DDT:
   - Army—Item No. 51–L–120—
     "Larvicide, DDT, powder, dissolving."
   - Navy—Standard Stock Catalog No. 51–I–157–5 and 51–I–157–25—
     "Insecticide concentrate powder."
2. Ten-percent DDT dusts:
   - Army—Item No. 51–I–173 (2-oz. can)
     Item No. 51–I–180 (bulk)—
     "Insecticide, powder, louse" (DDT in pyrophyllite).
   - Army—Item No. 51–L–122—
     "Larvicide, DDT, powder, dusting" (DDT in talc).
   - Navy—Naval Medical Supply Catalog No. F13–451—
     "Insecticide diluted powder" (DDT in talc or pyrophyllite).
3. DDT emulsion concentrate:
   - Army—Item No. 51–I–156–95—
     "Insecticide, DDT, emulsion concentrate."
   - Navy—Standard Stock Catalog No. 51–I–157–500—
     "Insecticide concentrate solution."
4. DDT residual spray:
   - Army—Item No. 51–I–305—
     "Insecticide, spray, DDT, residual effect" (5 percent DDT, 15 percent Velsicol AR–50, 80 percent kerosene).
5. DDT aerosol:
   - Army—Item No. 51–I–159.
6. DDT louse spray:
   - Army—Item No. 51–I–310—
     "Insecticide, DDT, spray, delousing" (emulsion concentrate formula NBIN, see page 55).
7. Repellents and miticides:
   - Army—Item No. 51–R–265—
     "Repellent, insect" (2-oz. bottles of dimethyl phthalate or 6-2-2 mixture, see page 59).
   - Army—Item No. 51–R–300—
     "Repellent, insect, spray, clothing" (bulk dimethyl phthalate).

III. DDT Larvicides for the Control of Anopheline and Other Mosquitoes

General Discussion

Research at Orlando, Fla., has led to the recommendation of DDT for the control of anopheline and certain other mosquito larvae. This material has proved outstandingly superior to other previously known larvicides. Since it is soluble in a number of organic solvents, including petroleum oils, it can be used in various ways that are not practicable with larvicides such as the arsenicals. Small quantities will control mosquito larvae in large breeding places. This simplifies the transportation and supply problems, which are especially important in combat areas.

DDT is poisonous and all recommendations for its use should be followed carefully (see further discussion on the toxicity of this material in Part X, under the heading "Discussion" on page 71.)

DDT can be used as a dust with inert diluents, in liquid form dissolved in oils or other solvents, or as an aqueous emulsion or suspension.

Emphasis has been given to the development of larvicides effective against anopheline mosquitoes, but certain culicine mosquitoes are likewise important because of annoyance or through the transmission of diseases. DDT is highly effective against both types of mosquitoes. Because of its high toxicity to mosquito larvae and the different ways in which it can be applied, the material can be employed as an all-purpose larvicide. It has been recommended to the Office of Scientific Research and Development for use by the armed forces in three forms—(1) in petroleum oils, (2) in concentrates for use in preparing aqueous emulsions, and (3) in dust form. The methods of applying DDT in these three forms with ground equipment will be discussed separately, and brief mention will be made of other methods which are being investigated. Application by means of aircraft will be discussed in Part V. Although the present discussion on the control of mosquito larvae is limited to the use of DDT, it should be emphasized that measures for permanent control of mosquito-breeding areas should be initiated whenever possible and feasible.

Anopheline Larvae

DDT IN PETROLEUM-OIL SOLUTIONS

Technical DDT (Larvicide, DDT, powder, dissolving, No. 51–L–120) is available for use as a larvicide. For use in oils it should be prepared at a concentration between 5 percent and less than 1 percent. At ordinary temperatures the crystals dissolve in oil rather slowly; it is therefore advisable to keep a reserve stock of such solutions on hand.

A 5-percent solution is prepared by adding about 2 pounds (2⅛ pounds for a true 5-percent weight-per-volume solution) of DDT to each 5 gallons of oil. Unless some heat, such as that provided by

exposure of the drum in sunlight, is used to hasten the action, as much as 24 hours may be required to dissolve the DDT. Kerosene, Diesel oil, fuel oil, or crankcase oil will dissolve the material. This concentrated solution can be applied directly where coverage can be obtained with small quantities of oil, but it can also be used to make dilutions as desired.

Although numerous methods of applying oils have been used in mosquito control, two methods of applying DDT in oil have been given most consideration. One method consists in spraying the material on the water, and the other in pouring or squirting oil containing DDT on the water surface.

Application with spray equipment

The most reliable method of applying larvicides under a wide range of conditions is by means of sprayers. Owing to the remarkable larvicidal action of DDT, the amounts of DDT spray needed are extremely small; one must realize this to take full advantage of the potential savings in materials and labor.

Oil without DDT is usually applied at the rate of about 15 to 35 gallons per acre for control of mosquito larvae. Comparable control can be obtained with 5 quarts per acre of a 1-percent DDT-oil solution when properly dispersed. With a 5-percent DDT solution as little as 1 to 2 quarts per acre is effective, when applied with the decontamination-type cylindrical sprayer (similar to the ordinary 3- to 4-gallon garden pressure sprayer). To obtain coverage when applying such small amounts, it is necessary to use a slow delivery of a fine mist. Since the equipment now available is difficult to adjust to deliver the small quantities needed, it is necessary to reduce the concentration of DDT to 1 percent or less and to apply a larger volume of oil solution.

The nozzle should be adjusted to deliver as fine a spray as possible and at a slow rate, and the spray should be applied so that it will drift over the water (fig. 1). A swath width of 50 feet is suggested, although experimentally, under favorable conditions, good control has been obtained for several hundred feet with a finely atomized spray of 5 percent of DDT in oil applied at the rate of 1 to 2 quarts per acre. By changing the aperture of decontamination-sprayer disks to about $^{3}/_{64}$ inch (Nos. 56–60 standard wire gage), the delivery rate of the standard spray equipment is reduced and a finer spray is obtained.

The type of nozzle used is shown dismantled in figure 2. With such adjustments it is usually possible to get effective coverage with 5 quarts of oil per acre, although larger quantities should be used if needed. Since 0.1 pound or even less of DDT per acre is all that is required for initial control, the concentration of DDT should be reduced to give this dosage. In difficult places larger quantities of spray may be required to obtain distribution, but it should be emphasized that effective control can be obtained with very low dosages. In order to reduce transportation of materials and labor, efforts should be made to apply minimum amounts.

Larvicides can be applied with power equipment mounted on vehicles.

Investigators with the United States Navy have reported excellent results in the Pacific area with ordinary hand sprayers of the Flit-gun type, and for many breeding areas this equipment is very satisfactory. This kind of equipment was also tested earlier by workers at the Orlando laboratory. These small sprayers are easily carried, and when 2.5- to 5-percent DDT solutions are used they contain enough material to treat many small breeding places. The use of the hand sprayer is shown in figure 3.

For residual toxicity, where wind and waves do not affect the surface, a dosage of 1 pound of DDT per acre should be used. For

FIGURE 1.—Use of decontamination-type cylindrical sprayer for the application of larvicides.

this dosage 2½ gallons of oil containing 5 percent of DDT will be required. If more oil is needed to obtain distribution, the percentage of DDT should be correspondingly reduced. For example, if 5 gallons of oil are required for adequate distribution over 1 acre, then the DDT concentration should be reduced to 2.5 percent. Heavy dosages of DDT may prove harmful to fish life and the higher dosages are not recommended in situations where this factor must be considered.

Application by pouring or use of squirt cans

The pouring method, first investigated by M. A. Barber of the United States Public Health Service, consists in applying oil containing DDT to the water surface, in the simplest manner possible. This method is suggested if spray equipment is not available. The oil is applied at different places in the pool or stream, and the dispersion of DDT is

FIGURE 2.—Nozzle (shown dismantled) of the decontamination-type cylindrical sprayer.

FIGURE 3.—Use of an ordinary 2-quart hand sprayer for the treatment of small breeding areas.

largely dependent on the spreading properties of the oil. In some situations remarkable kills of larvae have been obtained with relatively small quantities of oil applied in this manner. Waste crankcase oil was tested by Dr. Barber, and can be readily utilized for this method of control, although Diesel oil and fuel oil are also recommended.

The quantity of oil containing DDT that will be needed for the treatment of 1 acre of water surface depends on the amount of vegetation and debris present, and on other factors, such as biological films, that retard the spreading of the oil. When the oil used spreads readily, as little as 1 to 2 quarts of oil containing 5 percent of DDT per acre is effective if applied at several locations over the area.

The most serious objection to this method of application is the variability of the results. In some mosquito-breeding areas oils do not spread sufficiently to give a uniform kill, but where the method can be used effective applications can be made with a minimum of equipment and labor.

Simple devices such as squirt cans and medicine droppers have been used by workers in Australia for small, scattered breeding places.

DDT IN AN AQUEOUS EMULSION

Considerable effort has been devoted to the development of a concentrated DDT solution for use in preparing aqueous emulsion sprays (see Suspensions, p. 9). The emulsion concentrate recently recommended consists of DDT 25 percent, Triton X–100 (or 50 : 50 Span 20-Tween 20 emulsifier) 10 percent, and xylene 65 percent. For application the concentrate merely has to be diluted with water from any convenient source. Because a small quantity of the concentrate will control mosquito larvae over large areas, the supply problem is simplified. Furthermore, per unit of active ingredient, the emulsion is more effective than oil solutions against culicine mosquitoes. The emulsion produces larvicidal action when dispersed throughout the water. However, since the material has a tendency to remain concentrated on, or to rise to, the water surface when it is sprayed as a fine mist, the volume of water, within limits, need not be taken into account.

Upon dilution with water the emulsion is applied in the same manner as described for oils. A mixture of 1 volume of the 25-percent DDT concentrate and 4 volumes of water will give a spray containing 5 percent of DDT.

As in the case of oil solutions, if spray equipment is adjusted to produce a fine spray with a slow delivery, control can be obtained with small amounts of spray. Adequately distributed, 5 quarts of a 1-percent DDT spray will give effective control, but a lower concentration should be used if more spray is needed for coverage. For initial kill a dosage of 0.1 pound of DDT per acre is recommended. At this dosage 1 pint of concentrate (25-percent DDT) will control anopheline larvae on 2½ acres of breeding area. The use of oil containing DDT on the same area would necessitate transporting a minimum of 25 pints of oil, and the use of oil alone would require approximately 300 to 600 pints. The great saving in transportation with the DDT emulsion concentrate is therefore readily apparent.

The dosage of 0.1 pound of DDT per acre is considered an initial killing dosage without regard to any lasting effects. Some residual

action may result, and the time for repeating the treatment should be determined by dipping.

For dispersal in water the dosage is calculated on a parts-per-million basis. DDT applied at the rate of 1 p.p.m. in quiet pools will prevent breeding for several weeks. This dosage requires approximately 11 pints of the DDT concentrate per acre of water 1 foot deep. For such heavy dosages the concentrate should be diluted to the desired concentration of DDT and applied as a coarse spray. This will cause the spray to mix through the water, which is desired in this case. Since dosages larger than 1 part of DDT to 10 million parts of water may prove fatal to fish life, where fish are present residual dosages are not recommended. There are many situations, however, such as temporary pools, shell holes, and borrow pits, where fish are not present. In such places heavy applications of DDT are recommended in order to reduce the frequency of application.

DDT IN A QUICK-BREAKING OIL EMULSION

Where a strictly surface-acting emulsion is desired, the quick-breaking emulsion may be employed. Oil emulsions of this type, which break on the surface of the water, have previously been employed in mosquito control. The incorporation of DDT in such emulsions results in a very effective larvicide. Per unit of DDT it is equally as effective as the oil solutions, stable emulsions, and dusts. Three types of quick-breaking emulsions have been prepared.

Several kinds of oil-soluble emulsifiers are very effective (see Part II). About 3 percent of Triton X–100 has been found satisfactory. The oil should contain as much DDT as will dissolve. Five percent of DDT is suggested, but at high temperatures certain oils may dissolve a higher percentage. The oil containing DDT and the emulsifying agent can be diluted with water to obtain the desired concentration of DDT for application, as is done in the case of aqueous emulsions.

Ordinary laundry soap, which is not oil-soluble, has also been found useful for the preparation of a quick-breaking type of emulsion. Capt. W. C. McDuffie, on assignment in the Pacific area from the Office of the Surgeon General of the Army, has described a method of preparing an emulsion with which he obtained excellent results against mosquito larvae in field tests.

A quick-breaking oil emulsion may also be obtained by adding the DDT-xylene-Triton emulsion concentrate (see Emulsions, p. 7) to the fuel oil or other oils commonly used in mosquito control. One part of the concentrate may be added to 4 parts of oil, and the mixture then emulsified in water to obtain the desired concentration of DDT in the finished spray.

DDT IN DUST FORM

Research on the use of DDT in dust form has shown it to be about 25 times as toxic as paris green to larvae of *Anopheles quadrimaculatus* Say.

Control of *Anopheles* larvae can be obtained with 0.1 pound or less of DDT per acre in dust form. The technical grade of DDT has certain physical properties that make it less desirable for use as a dust than as a spray. On account of its waxy nature it is difficult to grind it to the desired degree of fineness without the addition of a diluent.

694035°—46——3

A finely ground powder that contains 10 percent of DDT is being produced for use by the armed services. However, 9 pounds of inert material must be shipped for each pound of active ingredient. There is

FIGURE 4.—Application of DDT larvicide dust with rotary hand duster.

also the problem of having on hand in the field extra quantities of diluent, as well as mixing equipment.

Where dusts can be supplied, the treatment can be used effectively and applied readily with ordinary ground dusting equipment (fig. 4). The 10-percent dust can be applied at the rate of 1 pound of dust per acre, but to obtain effective distribution a larger quantity of dust may

be necessary. The dust should then be further diluted to the desired percentage to obtain good coverage with a dosage of 0.1 pound of active ingredient per acre. Five pounds per acre of a 2-percent dust will prove satisfactory in most situations.

As with DDT in oil solutions, residual action can be obtained in some situations, especially in quiet breeding areas where vegetation is so dense as to prevent shifting of surface films due to wind or rain. In such places 1 pound of DDT per acre may give satisfactory control for several weeks after treatment. For residual treatments it is unnecessary to dilute the 10-percent dust, which may be applied at the rate of 10 pounds per acre. In open breeding areas with relatively sparse vegetation it is usually wasteful to apply more than 0.1 pound of DDT per acre, since the treatment, whether heavy or light, is likely to become ineffective within a week or two owing to drifting of the surface dust film.

OTHER METHODS OF APPLYING DDT

The methods that have been suggested for applying DDT larvicide are the ones most generally used. Under the wide range of mosquito-breeding conditions that exist throughout the world, other methods may also be satisfactory. DDT in oil solutions or aqueous emulsions may be used in drip cans. Sand, sawdust, or other materials treated with oil containing DDT may be broadcast in the same manner as combinations of paris green and oil. Other methods, such as DDT aqueous suspensions and bags of sawdust soaked in oil containing DDT, may also be employed.

Culicine Larvae

Although most emphasis has been placed on the development of anopheline larvicides, the same materials and methods of application have been tried on several species of culicine larvae. DDT is outstanding as a larvicide for various species of *Culex* and *Aedes* mosquitos. It proved to be at least 50 times as toxic as phenothiazine to larvae of *Culex quinquefasciatus* Say and *Aedes aegypti* (L.).

DDT IN PETROLEUM OILS

Control of certain pest mosquitoes, such as *Psorophora*, has been obtained with dosages as low as 0.1 pound per acre of DDT in fuel oil, although in general *Culex*, and to a lesser extent *Aedes*, requires a heavier dosage. For *Culex quinquefasciatus* dosages as high as 0.5 pound per acre of DDT in an oil solution are recommended.

DDT IN AN AQUEOUS EMULSION

DDT has been tested more extensively in the form of an emulsion than in oil solution or in dust form. DDT is much more effective in an emulsion than in oil solutions, especially against *Culex*. In field tests control has been obtained against *Aedes taeniorhynchus* (Wied.), *A. aegypti*, *A. sollicitans* (Walk.), *Psorophora ciliata* (F.), *P. columbiae* (D. and K.), *Culex nigripalpus* Theob., and *C. salinarius* Coq., at dosages as low as 0.05 p. p. m. Surface applications of 0.1 to 0.2 pound of DDT per acre, or a dosage throughout the water of at least 0.05 p. p. m., are recommended. The concentration of DDT to use in the

diluted spray to obtain these dosages will depend on the amount of spray required for adequate coverage.

Lt. R. P. Holdsworth, of the U. S. Naval Hospital, Key West, Fla., has cooperated in tests against *Culex* and *Aedes* breeding in cisterns, wells, cemetery urns, etc. The DDT emulsion proved more effective than DDT in oils under such conditions. In situations of this kind long-lasting dosages are recommended in order to reduce the frequency of treatment. Dosages ranging from 1 to 5 p. p. m. are suggested.

The DDT emulsion should be applied in the manner described for the control of *Anopheles* larvae. Higher dosages may be necessary for certain species, depending on the conditions under which they are breeding. The degree of water pollution is known to be one important factor to be considered. DDT is most toxic to fish life when in emulsion form, and, where fish are present, should not be applied in this manner except in very low concentrations.

DDT IN DUST FORM

DDT applied as a dust is not highly effective against larvae of *Culex* and *Aedes* that feed below the water surface, and at present dust applications are not recommended for them.

IV. DDT Insecticides for the Control of Adult Mosquitoes

General Discussion

The application of control measures against adult mosquitoes in many respects is even more important in time of war than in peacetime. This is especially true in a highly mobile type of warfare such as was used in World War II. The works of Ross (*3*), Covell *et al.* (*1*), Russell and Knipe (*4*), and others have fully demonstrated the value of destroying adult mosquitoes in buildings as a means of control for malaria. Troops entering an area where malaria and other mosquito-borne diseases are prevalent may be exposed for several weeks to infected vectors already present, even though larviciding operations or engineering measures for larval control are initiated at once. By the time antilarval measures are able to reduce the mosquito populations troops may move into new infected areas.

On the other hand, an effective and rapid means of destroying adult mosquitoes will reduce the spread of the disease immediately. For these reasons various ways of destroying adult mosquitoes have been extensively investigated. The progress has been remarkable, and effective methods are now in use that were never before employed. These developments have changed completely our concepts as to the most feasible and practical means of controlling mosquito-borne diseases under certain conditions.

The studies on adult-mosquito control have been along three major lines: (1) The development of DDT as a residual type of treatment for application in buildings and other sheltered areas where adult mosquitoes congregate; (2) investigations of aerosols and concentrated sprays for use as a temporary control measure in confined or semi-confined spaces; and (3) the development of sprays and equipment

for destroying adult mosquitoes under outdoor conditions. The first and third methods have not previously been employed as a means of controlling mosquito-borne diseases. The use of airplanes in applying sprays for destruction of adult and larval mosquitoes in area control is discussed in Part V of this report.

DDT as a Residual Deposit

The conventional method of destroying adult mosquitoes has been by applying contact sprays for initial or temporary control. The use of insecticidal residues has been given little consideration in the past. Early studies at Orlando established that residues of pyrethrum applied as a spray in appropriate concentrations were effective against bedbugs, and some preliminary studies with mosquitoes indicated similar possibilities. In fact, pyrethrum, together with certain activators, applied as a residual spray is very effective against mosquitoes. However, the shortage of pyrethrum prompted investigations on the residual action of other insecticides. These studies indicated little promise for some of the synthetic thiocyanates and other compounds, but when DDT became available its residue was effective against flies and mosquitoes for several months.

Excellent results obtained under various conditions in different parts of the world, and against many kinds of mosquitoes, have been reported by a number of men in the Army and Navy. On the basis of information already obtained, it is believed that residual treatments will prove to be the most generally effective and practical means known for the control of mosquito-borne diseases.

The major purpose of using DDT as a residual spray is to form a deposit that will kill adult mosquitoes when they rest or crawl over the treated areas as long as several months after treatment. To get maximum results the resting habits of the particular species to be controlled should be known, and for this reason specific directions for application of the insecticide cannot be given. The residual treatment will no doubt have its widest use in buildings, although it has shown much promise for the treatment of bed nets (see Application to Bed Nets, p. 24) and applied outdoors to vegetation harboring adult mosquitoes (see Application to Vegetation and Other Outdoor Resting Places, p. 24).

APPLICATION IN BUILDINGS AND OTHER SHELTERED AREAS

The following general procedure for applying DDT residual sprays (either kerosene solutions or aqueous emulsions) for control of mosquitoes around military establishments and native villages is suggested.

DDT solutions in kerosene

DDT may be dissolved in kerosene (Diesel or fuel oil can be used, but they are less effective) at a concentration of approximately 5 percent. The spray material can also be obtained already prepared under Quartermaster Item No. 51–I–305. Lower concentrations can be used, but to obtain the desired dosage of residual insecticides less liquid and labor are consumed if the higher concentrations are applied. The concentrations can be changed to meet the conditions as long as the desired dosage of active ingredient is applied.

The solution should be applied as a wet spray. Decontamination-type sprayers can be used, but the nozzle should be adjusted to make a fine but not a mist spray. A disk opening the size of a No. 60 standard wire gage is suggested. The ordinary paint-sprayer nozzle produces too fine a mist, and much of the spray may fall to the floor or escape into the air. If this is the only nozzle available it should be held close to the object to be sprayed, in order for the liquid to remain as a spray deposit. A wheelbarrow-type of sprayer has been found very satisfactory in practical field tests. An ordinary hand sprayer can also be used, but it requires considerable time and labor. The various types of equipment that can be employed in applying DDT residual

FIGURE 5.—Types of hand equipment that may be used for applying DDT residual treatments. Left to right: Paint brush, decontamination sprayer, 2-quart hand sprayer, plunger duster, wheelbarrow sprayer, and rotary hand duster. (Photo by AAFCTR, Orlando, Fla.)

treatments are shown in figure 5. Power sprayers can be used in the same manner (fig. 6).

The spray should be applied to the inside of dwellings, barracks, tents, latrines, mess halls, caves, and dugouts, under bridges, and to any other resting places for mosquitoes within the camp site. Particular attention should be given to the favorite resting places. This may include the entire inside of the dwelling, especially in the darker places, such as under beds and behind objects, in corners, etc. If screens are present, they should be treated also, but preferably by painting, since a spray would result in excessive waste. The many mosquitoes and other insects that alight on screens in their attempts to enter buildings

are thereby exposed to the insecticide, even though they do not succeed in entering the building.

The rate of application recommended at the present time is 200 mg. per square foot of surface. This represents the residue from 4 ml. of 5-percent DDT solution, which is equivalent to about 1 gallon per 1,000 square feet. At this rate a large barrack would require approximately 4 gallons of the spray. Studies at the Orlando laboratory and reports from certain investigators in the armed services have indicated good results with dosages as light as 50 mg. per square foot of surface, but the heavier dosages are indicated to be significantly more effective for several months after application.

In order that the residue method of control be available as near as possible to the front-line areas, tents should be treated before troops and equipment are moved forward. Any houses or other buildings within or near the camp site, any new constructions, or natural resting places for *Anopheles* should be treated as soon as possible after the area is occupied.

FIGURE 6.—Small power sprayer for use in applying DDT sprays. (Photo by AAFCTR, Orlando, Fla.)

Since mosquitoes in native villages are frequently the source of infection, the control or reduction of disease vectors in such areas will prevent spread of disease among troops. Where this situation exists, every effort should be made to treat the native habitations.

Although the methods suggested require considerable material and labor, a single application will remain effective against mosquitoes entering the treated building for 1½ to 5 months, and perhaps longer. It kills mosquitoes either before they have an opportunity to bite an infected patient or before they become capable of infecting man.

The residual-spray treatment will no doubt prove most effective against the domestic type of mosquitoes, which prefer dwellings for their daylight resting places. However, there is a good possibility that the treatment will also control diseases transmitted by vectors that do not usually stay in houses.

Although the residual treatment is intended primarily as a means of control for diseases such as malaria, dengue, filariasis, etc., it provides a considerable amount of relief from mosquito annoyance. In tests in the Stuttgart, Ark., rice-growing section the treatment of resting places for the adult *Anopheles quadrimaculatus* resulted in a substantial reduction of the larval population in the rice fields. Against more highly domesticated or shorter flying species residual treatments alone may result in a much greater reduction of mosquito larvae.

The use of kerosene in confined spaces may cause the operator discomfort due to irritation. Refined kerosene can be used, but to obtain concentrations of DDT as high as 5 percent some auxiliary solvent should be added. (See Part II.) Aqueous emulsions may be more desirable.

DDT in aqueous emulsions

The DDT emulsion concentrate (see formulas in Parts II and III) can be applied with the same equipment and by the same methods that are recommended for the kerosene spray. The emulsion has a number of advantages over the kerosene solution. The concentrate, which contains 25 percent of DDT, can be added to water for any desired concentration of spray solution. For most situations 1 volume of the concentrate to 4 volumes of water, which will produce a 5-percent DDT spray, is recommended.

APPLICATION TO BED NETS

The investigations by Naval Research Unit No. 2, operating in the Pacific area, showed that DDT residual deposits on bed nets are effective in controlling mosquitoes. The effect of the treatment against mosquitoes resting on the outside of the net apparently was not determined, but mosquitoes trapped in treated nets are readily killed. Nets may be treated by spraying or by dipping in a DDT emulsion.

APPLICATION TO VEGETATION AND OTHER OUTDOOR RESTING PLACES

Most species of culicine mosquitoes and a number of anophelines normally rest in heavily vegetated areas and enter dwellings only in search of blood meals. Studies were therefore conducted to determine the effect on the adult-mosquito population of heavy applications of DDT sprays, either oil solutions or emulsions, to vegetation and other resting places such as logs and ground litter. Tests were conducted primarily against *Aedes taeniorhynchus* in Florida, but similar observations were made by Capt. W. C. McDuffie in Panama against *Anopheles albimanus* Wied. and *Mansonia* spp.

In tests against *Aedes taeniorhynchus* 3 to 5 gallons per acre of an oil or emulsion spray containing 5 percent of DDT applied to vegetation and litter near the ground caused a great reduction of mosquitoes for several weeks after treatment. During the first 2 weeks the reduction on small plots ranged from about 80 to over 95 percent.

Although involving considerable labor and material, this method of protecting camp sites or bivouac areas may therefore prove highly practical in certain situations.

The spray may be applied with either a decontamination-type or

FIGURE 7.—Application of DDT with a decontamination sprayer as a residual spray to jungle vegetation for the control of adult mosquitoes. (Photo by AAFCTR, Orlando, Fla.)

a power sprayer (fig. 7). The spray should be as fine as possible, and well distributed on the lower 2 to 3 feet of vegetation and on ground litter where most mosquitoes are found resting.

694035°—46——4

Liquefied-Gas Aerosols and Concentrated Sprays

INDOOR USE

Liquefied-gas aerosols

The pyrethrum aerosol now in use is a modification of the aerosol first devised by W. N. Sullivan and L. D. Goodhue of the Bureau of Entomology and Plant Quarantine (Sullivan, Goodhue, and Fales 7). It consists of insecticides dissolved in a liquefied gas (dichloro-difluoromethane), which is confined in a 1-pound cylinder, or "bomb." When the gas containing the insecticide is released through its own pressure, the insecticide remains dispersed in the air in very fine particles. Developed in cooperation with the Army and Navy for greater economy in the use of pyrethrum, the aerosol provides an effective and convenient method of destroying mosquitoes in tents, barracks, billets, bomb shelters, and other somewhat confined spaces.

Directions for the application of aerosols are stamped on the dispenser bombs, and most of the military personnel are already familiar with their use. Since they are frequently used in excessive amounts, it is urged that these directions be carefully followed.

The pyrethrum-aerosol formula is not satisfactory for control of houseflies, when used at the dosage recommended for mosquitoes. Tests of DDT in the aerosol have shown that against flies this insecticide is much more effective than pyrethrum at concentrations that are practical. Pyrethrum is more effective against mosquitoes, and has a much more rapid paralytic action on insects. The presence of DDT also adds to the effectiveness of a pyrethrum aerosol against mosquitoes. Furthermore, studies indicate that the regular use of the DDT-pyrethrum aerosol may gradually build up a toxic residue on the walls and objects in tents, barracks, etc., which will kill some of the mosquitoes and flies that subsequently enter. The application of residual sprays is recommended, however, where control by residual action is desired.

Aerosols containing both DDT and pyrethrum have been recommended as a replacement for the straight pyrethrum aerosol and are now in use by the armed forces. A formula was developed which contains 0.4 percent of pyrethrins, 3 percent of DDT, 5 percent of cyclohexanone, and 5 percent of lubricating oil in Freon–12 (dichlorodifluoromethane), all percents by weight. The lubricating oil has been found to be equally as effective as the sesame oil, the activator in the pyrethrum aerosol. The cyclohexanone acts as an auxiliary solvent for DDT. Various modifications of the original DDT-pyrethrum formula have been under investigation at the Agricultural Research Center, at Beltsville, Md., as well as at the Orlando laboratory, and the formula now recommended contains 0.4 percent of pyrethrins, 3 percent of DDT, and 12 percent of APS–202 in Freon–12.

Concentrated sprays

In the past practically all research on insecticidal sprays was designed to determine the minimum concentration of insecticide that would control flies, mosquitoes, and similar insects. An effective dosage of insecticide with such sprays has necessitated the use of large quantities of liquid. Studies have shown that, if a spray is properly

applied, the amount of toxicant is the governing factor in insecticidal action and the amount of diluent is relatively unimportant. For example, in a given space 1 ml. of a 20-percent DDT spray is equally as effective as 20 ml. of a 1-percent spray. The same relationship exists with pyrethrum sprays.

This is highly important from the standpoint of transportation of spray material. It is also important in that the high concentrations permit the use of smaller and more efficient dispensing equipment. In areas where the transportation problem is so great that aerosols cannot be provided, highly concentrated sprays in light sprayers will be highly advantageous. Such equipment has been made and is now being tested. Further development of various types of spray equipment to dispense concentrated sprays is needed. With adequate equipment such sprays will treat about five to six times as much space per unit of spray material as will the liquefied-gas aerosol. Concentrated sprays are not self-propelled, like the liquefied-gas aerosols, but this disadvantage is offset by greater economy of the spray.

OUTDOOR USE (APPLICATION FROM THE GROUND)

Although sprays and aerosols are generally employed in confined spaces, studies have shown that they can be employed effectively under outdoor conditions as well. On the basis of these studies it appears possible to eliminate adult mosquitoes in relatively small areas. These methods should prove especially useful in making temporary mosquito-free areas for troops that are bivouaced, and also for those resting or working in a locality for a short time. For large areas airplanes enable us to lower the costs, speed the applications, and obtain greater protection. The dispersion of DDT sprays by means of airplanes is discussed in Part V of this report.

Tests with aerosols applied from the ground show that the standard pyrethrum bomb can be used to eliminate mosquitoes in thickly wooded areas. The aerosol is released as the operator walks back and forth in the area needing treatment. It should be released as close to the ground as possible, with swaths approximately 20 feet in width. Because the particles have a tendency to rise rapidly under some conditions, and most of the mosquitoes rest in the brush close to the ground, it is recommended that the bomb be tied to a stick and held within ½ to 1 foot of the ground. The contents of a 1-pound bomb have controlled *Aedes taeniorhynchus* in plots of 1 to 2 acres in thickly wooded areas.

Tests with aerosols in the jungle in Panama against *Anopheles albimanus* and *Mansonia* spp. have also given good results. Aerosols were especially effective in the quiet air prevailing in the dense jungle at night. To obtain full advantage of drifting aerosols any air movement that can be detected with tobacco smoke should be taken into consideration.

Finely atomized sprays containing 5 percent of DDT in kerosene have given excellent results on salt-marsh mosquitoes. The spray dispensed in 20-foot swaths from hand-operated DeVilbiss paint sprayers (fig. 8) at the rate of 0.5 to 1 pint per acre has reduced mosquito populations up to 99 percent. A mechanically operated paint sprayer mounted on a jeep may also be used. If a paint-type sprayer is not available, or if the vehicle cannot get through the vegetation, an

ordinary decontamination sprayer may be used. It should be adjusted to make a fine spray. This can be done by soldering the hole in the spray disk and reboring with a No. 60 to 74 wire-gage bit. With such equipment the application of 2 to 5 gallons per acre of

FIGURE 8.—Application of space spray in the jungle for the control of adult mosquitoes. (Photo by AAFCTR, Orlando, Fla.)

a 5-percent solution is suggested. It is difficult to cover an acre with less material in pressure or knapsack sprayers because of the rapid rate of discharge and the large particle size. Dosages greater than 5 gallons per acre have not only given immediate reduction of *Aedes taeniorhynchus* but have given 80 to 98 percent control for about 2

weeks. The spray should be applied by taking swaths approximately 10 to 20 feet wide.

When used against tropical anophelines, a heavy dosage of DDT applied to the foliage near the ground should be lethal to mosquitoes coming in contact with leaves for long periods. It is not known how large an area must be sprayed to obtain protection against different species, but in Panama good results against *Anopheles albimanus* were obtained in small plots. A thorough spraying in a small plot may give protection against certain species for several nights. Laboratory tests have demonstrated that, if the spray is allowed to dry on leaves, the DDT deposit is resistant to rains. The deposit can be washed off, however, when the leaves are still moist with the sprayed material. It is therefore suggested that attention be given to the weather conditions when applying residue spray on foliage.

DDT applied as a 5-percent dust at the rate of about 5 pounds per acre (0.25 pound of DDT) has also given good control of *Aedes* mosquitoes, although results have not been so good as with aerosols and sprays.

V. Airplane Application of DDT

General Discussion

DDT can be applied effectively from airplanes for the control of both larvae and adult mosquitoes. Airplanes were employed by W. V. King, of the Bureau of Entomology and Plant Quarantine, as early as 1923 for control of anopheline mosquito larvae in Louisiana. Since that time paris green and other arsenicals have been applied from aircraft extensively by the Tennessee Valley Authority and other agencies.

The development of DDT has greatly stimulated interest in the use of airplanes as a means of controlling mosquitoes. Two factors are primarily responsible. (1) It has been demonstrated for the first time that adult mosquitoes can be controlled economically and effectively under outdoor conditions. (2) The high toxicity of DDT has made possible the development of spray materials that are far more effective against larvae than the arsenical dusts previously employed.

The possibility of applying DDT from airplanes was investigated after it had been demonstrated that adult *Aedes taeniorhynchus* could be controlled outdoors with small amounts of DDT in the form of sprays and aerosols applied from the ground (see Part IV), and after excellent results had been obtained against larvae with small quantities of sprays and aerosols (see Part III). These studies were under way as early as the late summer and fall of 1943. To carry on these investigations, a rather simple portable spray unit was designed and developed by C. N. Husman and O. M. Longcoy. Tests with DDT sprays applied with this sprayer installed on an L–4 (Piper Cub) airplane demonstrated that adult mosquitoes could be controlled at dosages of 0.2 to 0.4 pound of DDT per acre. With the same equipment satisfactory control of anopheline larvae was obtained at dosages of 0.2 pound or less of DDT per acre. Other studies were made with DDT dusts applied with regular dusting equipment and DDT smokes applied through the exhaust of the plane.

Although satisfactory results were obtained from sprays applied by airplane, the load of the small plane was not sufficient for large-scale operations or for fast work in forward combat areas. Accordingly preliminary tests, in cooperation with the Army Air Forces Center (AAFC) at Orlando, Fla., made use of Chemical Warfare Service M–10 tanks on large, fast combat planes. These tests, begun in December 1943, were very promising. Following these early developments, extensive research was undertaken, in cooperation with various agencies, for the purpose of developing more effective sprays and more efficient means of dispersal with different kinds of airplanes. These studies were conducted by the Army Air Forces Board at Orlando; the British Commonwealth Scientific Office; the National Defense Research Committee; the Tennessee Valley Authority; the Bureau of Medicine and Surgery of the United States Navy; as well as various groups in combat areas. The Bureau of Entomology and Plant Quarantine cooperated, whenever possible, in the further development of better methods of applying DDT insecticides from airplanes.

As a result of much experimentation it appears that a number of methods of applying DDT sprays are effective and satisfactory. The biological results permit considerable variation in the type of equipment, size of the spray droplet, and kind of airplane employed. In selecting the most satisfactory equipment for general use, several factors must be taken into account, and further trials and experience in actual control operations will be needed to evaluate the different types of equipment and planes. In general, large, fast planes capable of carrying big pay loads are needed for control of large areas, especially in combat zones. For small areas or for small, scattered breeding places, a slow-flying, readily maneuverable plane has many advantages. Although rapid progress has been made and airplane spraying of DDT is already a practical control method, much needs to be known before the most efficient and economical equipment and planes can be recommended. The following discussion is concerned almost entirely with the smaller types of slow-flying planes.

Equipment for Use on Slow-Speed Aircraft

HUSMAN-LONGCOY SPRAY UNIT

L-series airplanes

The first type of airplane spray equipment developed and tested was designed for use on the L–4 (Piper Cub) airplane, since this was the only plane available for such studies, and it can be made available in many areas. The sprayer known as the Husman-Longcoy spray unit (fig. 9) consists of a 25-gallon aluminum tank mounted in the rear cockpit and held in place by bolting to the front-seat cross-member bracket and clamping to the rear-seat cross-member. It is designed so that no part of the tank or hose fittings comes in contact with any of the aircraft controls or cables. A baffle extends from the bottom to the top of the tank to furnish added support and also to keep the spray material from swashing from side to side. A float gage is installed in the tank so that the pilot can quickly determine at any time the amount of material remaining in the tank.

The material is delivered to the nozzles by means of a half-inch gear pump mounted on a bracket, which is clamped to the wing struts. The pump is powered by a wind-driven propeller (18 inches with 45° pitch) mounted on the pump shaft. The pump turns at approximately 1,800 r. p. m. with a forward air speed of 65 to 70 m. p. h., maintaining an operating pressure of approximately 50 pounds.

Six spray nozzles are mounted on the lower trailing edge of a venturi, which is held in place by four brackets clamped to the lower longerons of the fuselage. These nozzles were redesigned from a fern-type spraying nozzle. Each one consists of an orifice (No. 54 wire-

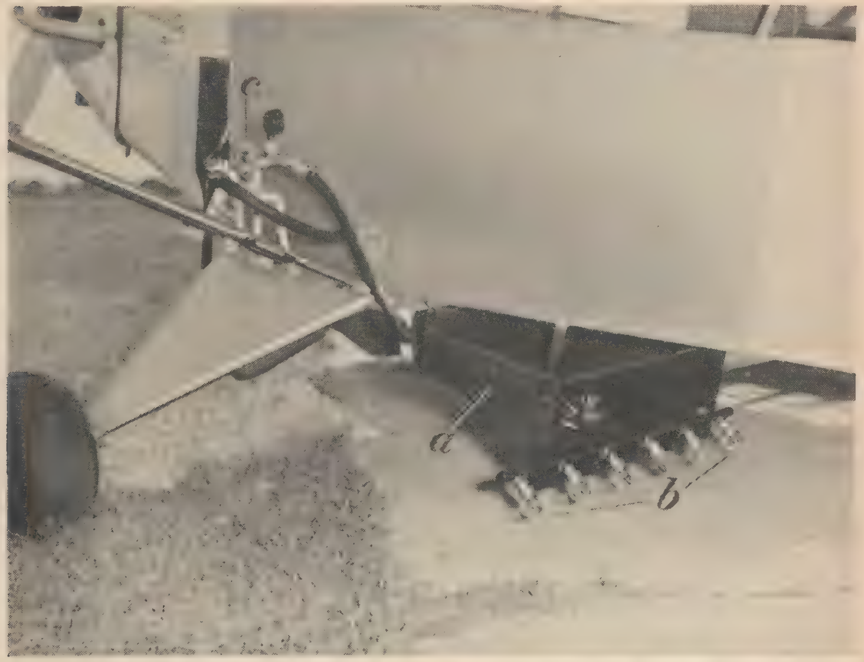

FIGURE 9.—*a*. Venturi, *b*. nozzles, and *c*. propeller-driven pump of the original Husman-Longcoy sprayer mounted on an L–4 (Piper Cub) airplane. (Photo by AAFCTR, Orlando, Fla.

drill size) which directs the liquid against a round, convex disk. The output of one nozzle is about 2⅓ quarts per minute. The venturi is used to keep the material from collecting on the fuselage and tail assembly of the airplane. The spray is turned on and off by means of a quick-cut-off valve mounted in the venturi and operated from the instrument panel in the front cockpit. This equipment is so designed and constructed that there is no structural change in any of the fuselage members, and it is installed so that the center of gravity is in the correct position.

A considerable number of these spray units have been built by the Army and made available for use overseas. Although the sprayer was designed especially for the L–4 (Piper Cub) plane, with slight modifications it can readily be installed on the L–2 (Taylorcraft) and the

L–3 (Aeronca). It also can be used on the L–5, although this plane will carry a heavier load of spray material and the spray tank should be increased in size accordingly. The Army Air Forces Board has recently modified the spray units for use in the L–5 plane.

PT–17 (Stearman) airplane

A spray unit of the same general design as that used on the L–4 was also made for the PT–17 (Stearman) plane. This consists of a 60-gallon aluminum tank mounted in the front cockpit by clamping the two vertical brackets, which are attached to the tank, to the bottom cross members on the fuselage. The rear of the tank is supported by the two vertical posts which formerly held the seat.

The material is delivered to the nozzles by a half-inch herringbone-gear pump. The bracket supporting the gear pump is clamped to the right side of the fuselage and the landing-gear strut. The pump is powered by a wind-driven 4-bladed propeller (18 inches with 30° pitch) mounted on the pump shaft. The propeller is equipped with a brake, which is controlled from the rear cockpit, so that the pump can be stopped when not in use. The pump turns at approximately 2,000 r. p. m. with a forward speed of 85 to 90 m. p. h., maintaining an operating pressure of approximately 100 pounds per square inch. Twelve spray nozzles are mounted on the lower trailing edge of the venturi, instead of six as used for the L–4. The nozzles are of the same type as those used on the L–4, but with No. 70 wire-drill openings. The material output is about 2⅓ quarts per minute per nozzle. The spray is turned on and off by means of a quick-shut-off valve mounted in the pressure line and operated from the instrument panel in the rear cockpit.

Where PT–17 airplanes are available, they are preferred to the L–series planes because of their larger pay load and greater maneuverability.

BREAKER-BAR SPRAYER

TBF and TBM airplanes

Other types of spray equipment have been designed for small planes. A device known as the breaker-bar spray unit, designed by an engineer from the Bureau of Entomology and Plant Quarantine, was recently built by the Navy for use on the TBM and TBF airplanes.

The equipment is designed for the distribution of 5 percent of DDT dissolved in Diesel and lubricating oils. Since it requires no structural changes in the plane, the aircraft can be kept in combat condition. The equipment can be removed or replaced in a short time without removing any ordnance gear. All materials used in the construction were procured from the aviation supply in the theater of operation, and no parts had to be specially ordered from the United States.

The bomb-bay auxiliary gas tank available for this aircraft is used as the insecticide spray tank. The only modification is the installation of four outlets to feed the four electric pumps. These outlets are mounted on the top of the tank, with four standpipes extending to the bottom. All other fittings, such as transmitter, filler, and breathers, are standard equipment.

Four electric auxiliary booster fuel pumps are mounted on a bracket that is the duplicate of the rear bracket supporting the tank. Two pieces of ¾-inch plywood are bolted to each side of these brackets. The brackets and pumps are mounted in the rear of the bomb-bay compartment, with working space between the tank and the pumps. The capacity of each of the four pumps is 400 gallons per hour. These pumps are adjusted to give 25 pounds' operating pressure at the nozzle.

Power is furnished to the pumps by the 24-volt electrical system of the plane. The wiring extends from the junction box, which is mounted on the rear port side of the bomb bay. The switch, which is

FIGURE 10.—Close-up of the TBM airplane showing the wing tip and breaker-bar spray boom mounted beneath.

mounted on the port side of the cockpit, just forward of the throttle, is in easy access to the pilot.

A spray boom, or tube, is suspended 12 inches beneath each wing, near the tip (fig. 10). The spray material is fed to the booms by two pumps connected by a Y to 1-inch (inside diameter) aluminum tubing.

A 1¼-inch hole is drilled in an inspection plate on each side of the fuselage, and a rubber grommet is installed in each hole. The 1-inch tubing leads out from the Y joint through these inspection plates, extending up to the lower part of the wings and then out to the spray booms. The tubing lies flush against the wing covering and is held in place by clamps. A short section of oil-resistant hose is installed in each line so that it can be uncoupled to allow the wings to fold. The

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spray booms and brackets are held in place with 10–36 drilled-head screws and are safety-wired.

Each spray boom, 92 inches long, is constructed of 1-inch (inside diameter) 0.035-inch side-wall, molybdenum-steel aircraft tubing. Nineteen orifices (No. 50 wire drill) are drilled, equally spaced, horizontally along 90 inches of the tube, the remaining 2 inches being left undrilled on one end of the boom for the hose connection. The spray booms are hung so that the spray is discharged to the rear of the plane. A duralumin spray-breaker bar, ¼ by 1 inch, with a 5° convex face, is attached to each spray boom, ½ inch behind the orifices, so that the spray will discharge against the face of the breaker bar. The spray is thus broken into comparatively small drops. These bars are bolted to the booms with drilled-head screws that are fitted with ½-inch spacers between the boom and the bar. The screws must be safety-wired.

Bracket plates constructed of 4- by 12- by $\frac{1}{16}$-inch steel are bolted to the wing at regular intervals with a thin piece of gasket material between the bracket and the wing. To these brackets are welded hangers, made of ½inch (inside diameter) 0.035-inch side-wall tubing. Cross braces are welded in the hangers for additional strength. Clamps in which the spray boom is held are welded to the bottom of the hangers.

The equipment delivers approximately 15 gallons of spray per minute. A swath of 150 feet is recommended at a dosage of 2 quarts per acre.

Modifications and improvements of this equipment have recently been made and installed on TBF airplanes at the Banana River Naval Air Station in Florida. The new equipment has longer spray booms and greater delivery of spray, so that a swath of 250 feet may be obtained at dosages of 2 quarts of spray per acre.

L-series airplanes

On the L–4 and L–5 series airplanes the breaker-bar spray mechanism of the TBM (with some variation) may be used in place of the venturi and nozzles of the Husman-Longcoy equipment. The breaker-bar sprayers for the L–4 and L–5 are similar, although they are not interchangeable. Specifications for the L–4 equipment may be obtained from the Orlando laboratory. The Army Air Forces Board constructed the L–5 equipment, and specifications may be obtained from this source.

The L–5 equipment consists of two spray booms mounted on the wing struts just outside the slip stream (fig. 11). The booms may be varied in length and number of orifices for use with sprays containing more than 5 percent of DDT. For a 5-percent spray the booms generally used on the L–5 plane are 62 inches long. Thirty-six orifices, of a No. 70 wire-drill size, are drilled, equally spaced, horizontally on 60 inches of the tube, leaving 2 inches of the tube undrilled on one end, so that the hose connection can be made. The duralumin spray-breaker bar is constructed identically, except for length, with that used on the TBM or TBF planes. The breaker bars are bolted to the booms so that there is a one-half inch space between the bar and the boom. Brackets clamped to the wing struts hold the booms in place. This mechanism

produces a swath width of about 80 to 120 feet when used on an L–5 plane, as compared with 40 to 60 feet for the venturi-type equipment. It also produces a more even distribution of spray within the swath. A four-bladed propeller, provided with a brake (fig. 12), is used in place of the two-bladed propeller used on the original venturi-type sprayer, thereby increasing the pressure and flow of the pump. The spray tank mounted in the rear cockpit is shown in figure 13. This is the same tank as that used with the Husman-Longcoy venturi-type sprayer.

When the breaker-bar equipment is to be used on the L–4 plane, the length of the booms generally used is 38 inches. Twenty-four orifices,

FIGURE 11.—Breaker-bar type of spray equipment for the L–5 airplane, showing the spray bar and propeller-driven pump. (Photo by AAFCTR, Orlando, Fla.)

of a No. 71 wire-drill size, are drilled, equally spaced, horizontally along 36 inches of each boom, the extra 2 inches being left undrilled for the hose connection from the pump. The booms and breaker bar may, as on the L–5, vary in number and size of orifice to suit the type of spray material used. A swath of 80 feet is recommended for this equipment, which delivers spray at the rate of 5 to 6 gallons per minute.

PT–17 (Stearman) airplane

The breaker-bar type of equipment has also been designed for the PT–17. The equipment used on this plane is similar to that designed for the L-series planes, except that each boom is 12 feet 6¾ inches long, having 50 orifices of a No. 70 wire-drill size. The booms are suspended 12 inches below each lower wing. Figure 14, shows a front

view of an equipped plane. The spray pump and propeller are the same as those used on the L–series plane; the tank, however, is located in the front cockpit.

This equipment delivers spray at the rate of about 10 gallons per minute. A swath of 110 feet is recommended at a dosage of approximately 2 quarts per acre.

FIGURE 12.—Close-up of the pump assembly of breaker-bar sprayer used on L–4, L–5 and PT–17 airplanes. This photo shows the four-bladed propeller and brake equipment.

ERHAUST-GENERATED SPRAY APPARATUS

The possibilities of utilizing the exhaust of a plane to disperse DDT were first investigated at the Orlando laboratory in 1943. When DDT solutions were injected into an extension of the exhaust pipe of an L–4 plane, an intense smoke was produced. Promising results were obtained with this equipment against both larvae and adult mosquitoes, when 10- to 20-percent DDT solutions were used. Figure 15 shows a PT–17 equipped with an exhaust generator. The Tennessee Valley

FIGURE 13.—Spray tank mounted in the rear cockpit of the L–5 airplane. (Photo by AAFCTR, Orlando, Fla.)

FIGURE 14.—Breaker-bar type of sprayer designed for PT-17, with spray booms beneath each lower wing. (Photo by AAFCTR, Orlando, Fla.)

Authority also tested this type of equipment installed on a Stearman plane, utilizing 15 to 20 percent of DDT in Velsicol NR–70. Excellent results were reported against larvae and adult mosquitoes.

Subsequent studies by several investigators have shown, however, that the smoke fraction (particles averaging 1 micron or less) was not the principal killing material. There was an incomplete conversion to the smoke phase, and some of the solution was discharged as a fine spray. The spray, no doubt, was responsible for killing most of the mosquitoes.

The National Defense Research Committee, at Urbana, Ill., working in cooperation with the Tennessee Valley Authority, then developed

FIGURE 15.—PT–17 applying exhaust type of heat-generated DDT spray.

a venturi within the exhaust pipe which produced a fine spray, or aerosol (25 percent of the spray was converted into droplets 5 to 25 microns in diameter), with only a small amount of screening smoke. Tests with this equipment against larvae and adult mosquitoes by TVA, and also at Orlando, showed excellent results. Special emphasis was then placed on heavy-pay-load sprays, and 20 percent of DDT in Velsicol NR–70 was utilized as the spray solution. The same type of equipment and spray material was then developed for use on the Navy TBM and tested in Florida and Panama with the Navy, National Defense Research Committee, Tennessee Valley Authority, and Bureau of Entomology and Plant Quarantine cooperating with the Army in Panama. Figure 16 shows the TBM applying the exhaust-venturi type of spray or aerosol.

The chief advantages of this kind of equipment and the highly

concentrated spray are that large areas can be treated with a single load and the presence of smoke aids the pilot in treating an area. Whether a fine spray of this type has advantages over somewhat coarser sprays has not been fully determined. Excellent results have been obtained with spray droplets averaging less than 100 microns and also with those averaging about 300 microns.

SPRAY EQUIPMENT FOR A HELICOPTER

Spray apparatus of several types installed on a helicopter has been investigated in a preliminary way by the Coast Guard and the Bureau

FIGURE 16.—Navy TBM airplane equipped with the exhaust-venturi equipment, applying DDT spray.

of Medicine and Surgery of the Navy, with the Bureau of Entomology and Plant Quarantine cooperating. The place of the helicopter in the application of insecticidal sprays has not been determined. For small areas that are not readily accessible with the conventional-type aircraft, the helicopter seems to have definite advantages.

Materials and Methods of Applying DDT From Aircraft

TYPES OF MATERIALS

Petroleum oil solutions

The same materials that are recommended for application from the ground can also be applied from aircraft. The spray materials that are most desirable are those generally available in combat theaters. The fuel or Diesel oil containing 5 percent of DDT can be improved,

however, by the addition of 10 to 20 percent (by volume) of motor oil (S. A. E. viscosity 10 to 50). The inclusion of motor oil reduces volatilization of the lighter oil fraction both before and after the spray reaches the water, ground, or vegetation; increases the toxicity of the material to both larvae and adults, possibly by inhibiting recrystallization of the DDT; and tends to increase the spreading power of the oil on the water surface.

Emulsions

The emulsion concentrate having the formula DDT 25, Triton X–100 (or 50 : 50 Span 20-Tween 20) 10, and xylene 65 percent may be used, as well as other emulsions discussed in Part II. The concentrate, diluted with water to obtain the desired percentage of DDT (5 percent or more), should be applied in the same manner and with the same dosage of DDT as suggested for the oil solutions.

Concentrated sprays

In the application of DDT sprays from aircraft it is desirable to apply the minimum amount of material that will give satisfactory control. If one-half the amount of a 10-percent or one-fourth the amount of a 20-percent DDT solution will give as good results as the full amount of a 5-percent solution, a single load of a plane will treat three to four times as much area. For this reason every effort is being made to determine the minimum amount of the higher concentrations that can be applied. The effectiveness of the treatment in relation to the amount of DDT and the amount of spray solution has not been fully determined. For use in buildings it has been shown that the amount of active ingredient is the governing factor for finely atomized sprays (see Outdoor Use (Application From the Ground), p. 27), and it seems likely that this may be true for open areas. An adequate distribution of small amounts of concentrated sprays means that smaller particles are likely to be used, and this in turn requires a consideration of climatic conditions, as well as other factors.

Several materials may be used for obtaining sprays with more than 5 percent of DDT in ordinary petroleum oils. A common method is to add a good solvent to increase the solubility in petroleum oils. A number of such auxiliary solvents are listed in Part II of this report. Cyclohexanone was employed as an auxiliary solvent in early tests in which the sprayer and exhaust smoke generator were used on Cub planes. This made it possible to use 10 to 20 percent of DDT.

If a high percentage of DDT is used, it may be feasible to employ a good solvent without a light oil such as kerosene. Velsicol NR–70 has been investigated extensively by the Tennessee Valley Authority and National Defense Research Committee in connection with the application of sprays by means of the exhaust-venturi sprayer installed on a Stearman plane. This solvent was also employed with the exhaust-venturi sprayer on the Navy TBM. Other solvents can be used in the same manner.

To obtain a higher concentration of DDT, the emulsion concentrate can be diluted with less water. To make a 10-percent DDT spray 1 part of the 25-percent DDT concentrate and 1½ parts of water may be used.

Dusts

Although DDT dusts are more difficult to apply from aircraft than are sprays, good control of mosquitoes can be obtained by their use. At present it is suggested that the concentration of DDT be not greater than 5 percent, because a higher concentration may affect the physical properties of the dust so that it will be difficult to obtain uniform coverage. Dusting equipment that is now used for applying paris green can be adapted to the application of DDT dusts.

METHODS OF APPLICATION

Since several types of planes and equipment may be employed, detailed instructions cannot be given for the application of sprays by aircraft. However, some general principles are discussed here that must be considered for any type of plane and spray apparatus.

The distribution of spray and the dosage of DDT will depend on a number of factors, such as the height of the plane, wind velocity and wind direction, droplet size, and the time of day. It may seem desirable to apply sprays at right angles to the direction of the wind, but it is not always feasible to fly cross wind. For this reason the spray pattern and swath width should be determined for flying with or into the wind as well as for cross wind. The minimum effective swath width obtained when flying with or into the wind should be used in all routine spraying of large areas under variable wind conditions. However, where conditions permit, the spray applications should be made by flying cross wind. The latter gives a wider swath, but the overlapping swaths insure a more equal distribution of spray.

It is necessary, however, to maintain the minimum effective swath width to obtain the desired dosage of DDT under a wide range of conditions. Good results have been obtained by a Cub plane (L–4) equipped with the Husman-Longcoy spray equipment flying 40- to 60-foot swaths. When the breaker-bar equipment is used on the L–4, an 80-foot swath is indicated to be satisfactory. The TBM, employing the breaker bar, attained an effective 150-foot swath when flying an altitude of 125 to 150 feet at a speed of 115 knots. The equipment designed by the Army Air Forces Board for the B–25 and the C–47 has given effective distribution over a swath at least 300 feet wide when sprays were applied from a height of 150 feet. The Navy TBM, employing the exhaust-venturi spray apparatus and flying about 50 feet above the jungle canopy, gave good results with 200-foot swaths. The PT–17, equipped with the Husman-Longcoy sprayer, produced an effective swath of 80 feet; when equipped with the breaker bar, the swath can be increased to 120 feet. A wider swath can be obtained with the various types of equipment and planes, but in general the widths mentioned might be considered the minimum effective swaths.

The amount of spray to apply will depend on the concentration of DDT, the type of cover, whether it is used against larvae or adult mosquitoes, the species involved, weather conditions, and other factors. In fact, the minimum effective dosage to recommend has not been fully determined. Good results against anopheline larvae have been obtained repeatedly with a 5-percent DDT solution applied from

the Cub plane at the rate of 2 quarts per acre. Experimentally, under favorable conditions, effective control has been obtained with a dosage of 1 pint per acre (0.05 pound of DDT). Workers at Tennessee Valley Authority have reported excellent results with exhaust smokes and sprays applying 0.05 pound or less of DDT when using a 15- to 20-percent solution in Velsicol.

Against adult mosquitoes effective control of *Aedes taeniorhynchus* has been obtained with 2 quarts per acre of a 5-percent solution when applied early in the morning from a Cub plane. The same dosage later in the day, however, in some cases gave poor results. Excellent results against *Anopheles albimanus* and *Mansonia spp.* were obtained with 2 quarts per acre of a 10-percent DDT solution (0.4 pound of DDT per acre) applied from the Cub plane.

Excellent results were also obtained in Panama with the Navy TBM–IC applying approximately 0.4 pound of DDT per acre. When the Army Air Forces Board equipment was used, effective control of *Anopheles albimanus* and *Mansonia* spp. was obtained with 0.3 to 0.8 pound of DDT per acre. No significant difference in the percentage of control was established between the low and high dosages.

The most effective droplet size to employ varies with the time of day and with other factors. In general, sprays having particles ranging from about 20 to 300 microns in diameter are satisfactory under a wide range of conditions.

The pilot is the key man in the application of aerial sprays. The success of a control operation will largely depend on how well the pilot covers the area treated. He should be thoroughly acquainted with the problem, and should work closely with those directing mosquito control. Operations run more smoothly after the ground men and pilots have worked together long enough to have a common understanding of the problem.

The pilot should also be thoroughly familiar with the pattern of the spray produced by the aircraft he is flying, including the amount of drift under different heights and wind velocities. In open areas where there are no obstructions, it may be desirable to fly light aircraft as low as 35 feet above the ground. In a strong wind low flying prevents excessive drift. With light planes sprays should not be applied when the wind exceeds 15 m. p. h. A breeze of 3 to 5 m. p. h. is an advantage, as the drift causes the spray from successive swaths to overlap. Whenever possible, sprays should be applied early in the morning, for wind conditions are usually most favorable at that time.

Pilots, especially those who have had no experience in swath-width work, or who have not applied dusts or sprays, should be trained before they are assigned to airplane spraying. It is of primary importance that they be guided for the swath width until they have demonstrated that they can fly even swaths without assistance. In open areas flagmen may be placed at each end of the area to be treated, and in wooded areas meteorological balloons may be anchored. Each time the pilot flies over the markers the men move over the required number of feet to indicate the next swath. Many pilots soon learn to judge this distance and do not require flagmen except in difficult terrain or under unusual situations. Aerial photographs with grid markings are helpful. A light radio would be a distinct advantage

for directing spot spraying. A 40-pound transmitter and receiver is available for communication with the TBF or SB2C aircraft.

Large aircraft, such as TBM, B–25, SB2C, and C–47, are difficult to maneuver and should be used only for large areas and long swaths. They carry large loads, and less time is consumed for landing and refilling than with the smaller planes. Their greater speed and longer range of flight allow them to be used considerable distances from the reloading base. Small areas requiring short runs are handled satisfactorily by small aircraft or by hand application.

The spray tank on aircraft can be filled from a trailer tank equipped with a power pump. Small power units can be employed for the

FIGURE 17.—The small power spray unit shown in figure 6 modified slightly and used as a transfer pump for loading planes. (Photo by AAFCTR, Orlando, Fla.)

small planes (fig. 17). Standard Chemical Warfare Service equipment has been found very useful for mixing and loading spray materials.

Methods of Evaluating Airplane Applications of DDT Sprays

Suitable methods should be employed to determine the effectiveness of the initial treatment, and population checks should be made at various intervals after treatment to obtain information as to the frequency of application. The destruction of both larvae and adult mosquitoes in large areas may reduce the population to the extent that there is a slow return to normal abundance. On the other hand, mosquitoes may migrate into treated areas within a relatively short

period. To evaluate treatments for larval control, the usual dipping procedures are used. The residual action of DDT may influence the adult-mosquito population, or the reduction of larval breeding may decrease the number of adults emerging. The dual treatment for larvae and adults may therefore prove highly effective in reducing the mosquito population.

Several methods of determining the adult-mosquito population have been used. In early work in Florida, Arkansas, and Panama landing or biting counts were made. Prior to treatment the mosquitoes that landed on the front part of the body and clothing were counted during a definite time interval (usually 1 to 2 minutes when mosquito populations were high). After treatment, usually after 6 and 24 hours, counts were made again in the same manner, and compared with similar counts made in an untreated area nearby. The method is satisfactory for large populations of species that bite during the day.

The landing- or biting-rate method may not prove satisfactory for counting night biters, especially when the mosquito population is low. This method has been used, however, by experienced men making counts with flashlights.

A second method is to count the number of mosquitoes in the daytime resting places, such as buildings, bridges, and hollow logs, before and after treatment. This method is especially applicable to *Anopheles* and other mosquitoes that can be found in considerable numbers in their resting places.

A third method, which proved to be excellent, was employed by the Army Air Forces Board and the Army Ground Forces in Panama. Records were obtained on mosquitoes caught in horse traps. The traps were designed so as to allow mosquitoes to enter but not to escape. No doubt other warm-blooded animals could be used instead of horses.

VI. Insecticides for the Control of Miscellaneous Insects

General Discussion

The use of insecticides for the control of adult mosquitoes was discussed in Part IV of this report. In general, the same principles and methods of application of DDT sprays and aerosols can be employed against a number of other important insects. Specific studies have been made with DDT as a means of control for houseflies, fleas, bedbugs, and cockroaches. Certain observations have also been made against sand flies, silverfish, and certain species of ants. DDT and other materials have also been employed as a means of protecting corpses from flies. The habits of the species and conditions of use must be taken into account in order to apply the materials properly and with the best results.

Flies

ADULTS

Laboratory and field studies at the Orlando laboratory and subsequent practical tests on a much larger scale conducted by the Corps of Engineers, Fourth Service Command, have fully demonstrated the

effectiveness of residual applications of DDT for the control of adult houseflies (*Musca domestica* L.) around military establishments. The treatment has also been found effective against adult blowflies (Calliphoridae).

Either kerosene or emulsion sprays containing 5 percent of DDT can be used with decontamination-type sprayers or other mechanical equipment. The spray should be applied so as to leave a residue on surfaces where flies congregate. A dosage of 200 milligrams of DDT per square foot or 1 gallon of a 5-percent solution per 1,000 square feet of surface is recommended. The spray should be applied to the

FIGURE 18.—DDT being applied with a decontamination-type sprayer as a residual spray for the control of houseflies in a dairy barn.

favorable resting places of flies on walls and ceilings of mess halls and kitchens, and to the inside and outside of window and door screens. Garbage racks, G. I. cans, and latrines should also be thoroughly treated.

If the military establishment is located near farms or dairies or other places where flies congregate, the favorable resting places should be treated. It is important to get at the source of the fly population, if possible, and the thorough treatment of the barns, stables, and the surfaces of barnyard manure piles on adjoining farms will greatly alleviate the situation on the military reservation. Figure 18 shows the application of a residual spray with a decontamination-type sprayer in a dairy barn.

A thorough residual treatment will last for several months. When such spray treatments are not exposed to sunlight, they continue to

kill flies for an entire year. The treatment of dairy installations near Orlando resulted in over 95 percent reduction in the fly population for at least 4 months.

LARVAE

Pit latrines

Research on the control of fly larvae has been started in recent months. Reports from combat areas emphasized the importance of flies, and DDT was reported to be of little value in the control of fly larvae. Studies made by Maj. Franklin Sherman III in the southwest Pacific area showed a common insecticide, paradichlorobenzene, to be highly effective in the control of fly larvae breeding in airtight pit latrines.

At the request of the Office of the Surgeon General of the Army, studies were undertaken to determine the value of DDT and paradichlorobenzene for the control of fly larvae. Various tests were made in which artificial fly-breeding media were substituted for fecal matter. These studies in general confirm the observations of Major Sherman, and for use in airtight pit latrines paradichlorobenzene is indicated to be highly effective against housefly larvae. The paradichlorobenzene acts as a fumigant and remains effective for 3 to 4 days when used at the rate of 20 gm. per square foot. There are indications that the insecticide also has repellent properties and will destroy adult flies that enter the pit. It is also strongly ovicidal under these conditions; eggs are killed by lower dosages than are required for the larvae.

Preliminary studies indicate that orthodichlorobenzene is also very effective, and has the added advantage that it will immediately stop gross infestations of maggots in dead bodies.

Used as a dust, or in emulsions or oil solutions, DDT proved relatively ineffective against the fly larvae, but the residue killed a high percentage of the adults that emerged.

Because paradichlorobenzene is more or less specific for use in pit latrines, it will not protect military installations from flies entering the reservation, and for this purpose DDT should be employed as a residual spray. DDT residual treatments alone in latrines have proved entirely effective and satisfactory in military establishments in the United States, and excellent results have also been reported from certain active theaters of war. Further studies on the control of fly larvae are under way.

Corpses

The prevention of blowfly-maggot infestations in corpses on the battlefield has been reported as a serious problem, and the emerging adults can create a serious fly menace.

DDT sprays unfortunately will not stop a larval infestation in the carcasses of animals, but a 5-percent DDT spray applied thoroughly before maggots develop (within 4 hours after death of the animal) has given good control. About 4 quarts of DDT solution per 150-pound body should be applied, giving particular attention to the under side of the bodies. If sprayers are not available, a sprinkling device can be improvised by punching holes in a bucket or can. When bodies cannot be sprayed until after the fly larvae have developed and migrated, it is suggested that the surrounding area (within a radius of

25 feet), including the ground, grass, and shrubs, be sprayed with 5-percent DDT at the rate of 5 gallons per acre so that the emerging adults will be killed.

Sodium arsenite has been used for this purpose, but it does not appear to be entirely satisfactory at concentrations of less than 2.5 percent under conditions in Florida. This chemical requires several hours to immobilize and kill larvae.

Extensive tests in Florida have shown that orthodichlorobenzene is highly effective in immediately stopping the activity of larvae. This chemical does not generally give such good results when diluted, although under some conditions satisfactory control has been obtained with dilutions as low as 20 percent in fuel oil. It has been found that the addition of DDT to this larvicide, as well as to others, is highly desirable. It aids in preventing reinfestation, and the residual effects of the DDT destroy practically all adult flies alighting on the carcasses.

Acetylene tetrachloride, first used by the Chemical Warfare Service, is another good larvicide. The action on the larvae is very fast.

Benzene hexachloride is also very promising for use on corpses, our findings confirming those reported by certain British workers. Emulsions containing 20 percent of this material in benzene have given excellent results when used in concentrations as low as 1 percent at the rate of 1 pint per 25 pounds of carcass. This mixture immobilizes the larvae in a few minutes, and a large percentage of adults subsequently attracted to the carcasses also succumb. Because it is effective at high dilutions, this mixture should be very useful for battlefield sanitation of cadavers, since it simplifies transportation and supply problems. Good emulsions of benzene hexachloride can be made with other solvents, such as xylene and Solvesso No. 3, but the larvae are not immobilized so quickly as when benzene is used. Studies on this problem are being continued, and several materials are sufficiently promising to be tested in combat areas.

Bedbugs

Extensive laboratory and practical tests have fully established the value of DDT for the control of bedbugs (*Cimex lectularius* L. and *C. hemipterus* F.). This insect can be eradicated from dwellings and army barracks by the thorough application of a 5-percent DDT spray to the beds and into the cracks and crevices in walls. Either a kerosene solution or an emulsion may be used. It can be applied with knapsack-type sprayers or power equipment. An atomized spray should be avoided, if possible, but if used the nozzle should be held close to the surface so as to obtain a wet spray.

In treating a bed it is important to get complete coverage of the entire mattress, spring, and bedstead. This will require about 100 ml. of spray. The application of a spray to a mattress is shown in figure 19. The spray should be directed particularly to the springs, joints, and corners. Barracks walls also should be treated to a height of about 6 feet, with special attention to the cracks and crevices where the bugs hide. Although the spray is highly effective in destroying the bugs contacted, it is almost impossible to reach all of them in their

hiding places. Since the DDT residue remains on the walls, bedsteads, springs, and mattresses, it will kill any bugs that later crawl or attempt to hide in places that have been treated. About 3 gallons of spray is required to treat all beds, side walls, and supports of a 74-man barracks. A single application, as described, has completely eliminated bedbug populations, and reinfestations have not occurred during a

FIGURE 19.—Application of DDT-kerosene spray for the control of bedbugs. (Photo by AAFCTR, Orlando, Fla.)

period of at least 9 months. Sufficient time has not yet elapsed to determine the maximum period of protection.

The first large-scale experiment with DDT against bedbugs was conducted under the direction of Lt. Col. J. Q. A. Daniels, AAFC, at Orlando. The results fully demonstrated the value of DDT as an effective and practical method of control. Similar tests by the Fourth Service Command and others have also shown that DDT residual spray, when properly applied, is highly effective for the control of bedbugs.

Where sprays can be applied, they are recommended for bedbug

control, but DDT in dust form is also effective. Troops provided with DDT louse powder can obtain protection by applying it to their beds, bedding, and cracks in the walls. Owing to the slow action of the DDT, complete protection from annoyance may not be obtained the first night.

Fleas

DDT sprays have been found highly effective against cat fleas (*Ctenocephalides felis* (Bouché)) and dog fleas (*C. canis* (Curt.)) in or around buildings. The sprays should be applied on the floor and about 2 feet up on the walls at the dosage recommended for flies and mosquitoes. In living quarters a light spray should also be applied to beds and bedding. On earthen floors the dosage must be increased, because walking stirs and mixes the soil with much of the DDT, so that it is not available on the surface for contact with adult fleas. One gallon of 5-percent DDT in oil, sprayed lightly over areas of 1,000 to 2,000 square feet, has completely eradicated fleas.

DDT in dust form has been used successfully in buildings with wooden or other hard-surface floors and on earthen floors where the soil is undisturbed by man or animals. The dust should also be applied to beds and bedding, and on other places where fleas may be found. DDT powder used in the same manner as in the body louse treatment is recommended for fleas on infested people. For use on dogs a 10-percent DDT powder, applied in the same way as an ordinary flea powder, is recommended.

In some parts of the world fleas are carriers of serious diseases, and in such areas the treatment of buildings and other infested places, as well as the person, may prove urgent. (See also Part VIII for the use of flea repellents.)

Cockroaches

A dust containing 10 percent or a spray containing 5 percent of DDT is recommended for control of cockroaches. The dust should be applied as recommended for pyrethrum dusts or sodium fluoride. Several types of hand dusting equipment are available. It is important to apply the powder liberally and thoroughly to cracks and crevices, behind objects, and along favorite runways of roaches (fig. 20). The visible dust can be removed in a day or two, but no effort should be made to remove the dust from cracks, crevices, and other places where its presence is not objectionable. Applications should be repeated in 6 weeks, even if the roaches appear to be under control.

DDT residual sprays, if thoroughly and heavily applied, are also effective, especially against the American cockroach (*Periplaneta americana* (L.)). Special attention should be given to cracks and crevices, under side of tables, drainboards, sinks, etc. The spray usually acts more slowly than the dusts.

Other Insects

Among other important insects that can be readily controlled by DDT residual sprays are sand flies (*Phlebotomus* spp. and *Culicoides* spp.). Studies on *Phlebotomus* were made by Maj. Marshall Hertig,

on assignment at the Gorgas Memorial Laboratory, Panama Canal Zone, by the Office of the Surgeon General. The principles and dosages suggested for mosquitoes (see Part IV) were followed in carrying out the studies, and effective control has been reported. Considerable relief from *Culicoides* can be obtained by the treatment of window screens with a heavy oil containing 5 percent of DDT, as well as by applications of a residual spray inside of quarters.

Silverfish (*Lepisma saccharina* L.) can be controlled by residual sprays and dusts. Certain species of ants have been kept under control in homes by applying DDT residual sprays to baseboards, window sills, sinks, and other places where ants congregate. They usually enter dwellings from nests located outdoors, and if the nest is found a dust may be sprinkled about the opening of the nest.

FIGURE 20.—DDT dust being applied to cracks in a mess hall with a plunger-type duster for the control of roaches.

VII. Control of Human Lice and Scabies

General Discussion

Three kinds of lice attack man, namely, the body louse (*Pediculus humanus corporis* Deg.), the head louse (*P. humanus humanus* (L.)), and the crab louse (*Phthirus pubis* (L.)). Because of the wide differences in habits, each requires special consideration in applying control methods. Since the body louse is the principal vector of typhus and other louse-borne diseases, emphasis has been placed on the develop-

ment of control measures for this louse. However, because of its close morphological and biological relationship to the head louse, the latter form may also be incriminated as a transmitter of diseases. The crab louse is not known to transmit any disease, but it does cause much irritation of the skin. Since it is cosmopolitan in distribution and is common among troops and civilians, effective methods of control are necessary.

Intensive research under laboratory and simulated natural conditions led to recommendations and use of the louse treatments that are discussed herein. Additional information on the use of these treatments under field conditions and upon improved methods of application in the field received special attention from Col. W. S. Stone and his associates in the armed forces, and members of the United States of America Typhus Commission and the Rockefeller Foundation.

Scabies, or human itch, is caused by a small mite (*Sarcoptes scabiei hominis* (Hering)) which burrows through the horny layer of the skin. The disease is common in this country, but the incidence is usually not high among military personnel. In certain other countries the incidence is much higher and it is considered to be an important military problem. In any case definite control measures are necessary, and in this laboratory an attempt has been made to develop a single treatment that can be used for both lice and scabies.

This report is concerned only with treatments recommended by the Orlando laboratory to the Office of Scientific Research and Development for use by the armed forces, although other control methods are also in use. The treatments to be described include powders, liquid preparations, and impregnated garments. The various formulas and details regarding their use are discussed on the following pages.

Control of Body Lice

The body louse, which is frequently called the clothes louse, usually spends its life in the clothes, but it occasionally lays eggs on the hairs of the body and is known to cling to the host when the clothing is removed. In looking for body louse infestations, one should examine the clothing along the seams and folds, especially on the inside of the underwear. Because of the habits of this species, control measures should be directed largely toward the treatment of clothing. Louse powders are now issued to the armed forces, and materials and equipment for impregnating garments may be available in the future. The two powders issued for use in louse control are the MYL and DDT powders. The DDT powder is superior to MYL in that it retains its toxicity over a longer period of time. Since both have been issued, methods of application are given for each.

LOUSE POWDERS

DDT powder

This powder, consisting of 10 percent (by weight) of DDT in pyrophyllite, is available in 2-ounce sifter-top cans for use by the individual, and is also available in bulk for application to large numbers of persons by means of mechanical dusters.

Application by the individual.—A liberal application of the powder from the sifter-top can should be made over the entire inner surface of

the underwear, special attention being paid to the seams. As the powder is applied, it should be distributed as evenly as possible by hand. The seams of the inside of the shirt and trousers should be treated in a similar manner. The application of a louse powder for individual protection is demonstrated in figure 21. Approximately 1 ounce of powder, or one-half the contents of the can, will be necessary for one application.

The treatment is highly effective against body lice. Although slower in action than the MYL powder (which will be discussed later), it is not so slow acting as is generally believed, since lice that come into contact with it are immobilized in about 6 hours and all lice

FIGURE 21.—Individuals applying louse powder from the 2-ounce can to the inside of the underwear.

on the individual can usually be killed in 24 hours. The powder is not ovicidal; eggs are not destroyed by the treatment. Owing to its long-lasting action, however, complete control of lice hatching from eggs in clothing or bedding can be expected for 3 weeks and a high degree of control for a month after treatment. As eggs of body lice normally hatch in less than 2 weeks and seldom after 3 weeks, a single application should eradicate the infestation. Since the lasting effect of the treatment is due to residual action of the powder remaining on the treated clothing, it will be necessary to reapply the powder if the underwear is changed.

If infestations are present in stabilized military units, every individual should be treated in the manner described, and all personnel should be treated at about the same time. The powder should also

be dusted in the bedding between the sheets and blankets and on the mattress.

Persons not infested with lice but mingling with lousy troops or civilians, or living in infested quarters, should apply the powder in the manner described to prevent infestations. Medical officers, nurses, other medical attendants, and Red Cross workers should apply the powder as a prophylactic measure.

Although it is desirable to apply the powder thoroughly and uniformly to the clothing, soldiers in the field may not find it possible to remove their clothing for treatment. Experiments indicate that complete control of lice can be obtained without removing clothing by unbuttoning the shirt and trousers and distributing the powder as effectively as possible by dusting the inside of the underwear, shirt, and trousers.

Mass treatment with dusting equipment.—This method of treatment has not been investigated at the Orlando laboratory. Methods of application for the control of lice among large bodies of troops or civilians by use of mechanical dusters were first developed in the North African theater by Col. W. S. Stone and members of the Rockefeller Foundation. The method is complete and thorough and, if followed, will completely eradicate lice from infested units. In brief, the procedure is as follows:

The powder should be dusted or blown [8] between the innermost garment and the skin and between all other layers of clothing worn by the individual (fig. 22). Special attention should be given the innermost garment, since most of the lice are found there. The powder should be blown up the sleeves and into the shirt from the back and in front. After the trousers are loosened, the powder should be applied to buttock and scrotal regions and also blown down the trouser legs. About 1½ ounces per person has been found sufficient. The bedding or any extra clothing should also be thoroughly dusted.

MYL powder

This powder was developed prior to the recommendation of the DDT treatment. It is composed of the following ingredients: 0.2 percent of pyrethrins, 2 percent of N-isobutylundecylenamide, 2 percent of 2, 4-dinitroanisole, and 0.25 percent of Phenol S (isopropyl cresols, byproduct of thymol manufacture) in pyrophyllite (all percents by weight). Although less effective than the DDT powder, the MYL formula can be relied upon to control louse infestations when used according to directions.

In initial killing action MYL powder is equal to the DDT powder, but the residual action is not nearly so great. The formula contains an ovicide, which under most conditions gives control of eggs contacted. Owing to the difficulty of contacting all eggs in the clothing, however, it is almost impossible to control an infestation by killing all lice and eggs with a single application.

The MYL powder cannot be depended upon to kill lice over a period longer than 1 week after application to clothing. For this reason a second application is required. The same directions for applications can be followed as given for the DDT powder.

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[8] The Quartermaster now issues a special duster for delousing, Item No. 41–D–3755.

IMPREGNATION OF GARMENTS

DDT has been found exceptionally effective and long lasting when impregnated into clothing. Although the mechanics of treatment and the distribution of impregnated garments to military personnel

FIGURE 22.—Louse powder being applied to an individual with a hand dust gun. (Photo by AAFCTR, Orlando, Fla.)

may present some difficulty, the method largely eliminates the personal factor and provides more permanent control of body lice than the use of powder. When impregnated with the recommended dosages of DDT, garments worn continuously but washed once each week are effective in eliminating lice for 6 to 8 weeks. The garments are effective for much longer periods when not washed. Troops provided with two DDT-impregnated garments would probably remain free

of lice during the winter, when lice are most prevalent. In general, a dosage of DDT amounting to about 2 percent of the dry weight of the garment is recommended.

Two methods of impregnating garments may be used, the volatile-solvent method and the aqueous-emulsion method.

By the first method the underwear is dipped into dry-cleaning solution, such as Stoddard solvent or gasoline, containing 1 to 2 percent of DDT, depending on the amount of solution retained by the cloth. The excess solution is removed by wringing, and the solvent is allowed to evaporate before the garments are worn. This method would be most useful where regular dry-cleaning equipment could be utilized. The percentage of DDT needed in the solution will depend on the amount of liquid remaining in the clothing after the whirling process, but a retained dosage of 15 to 20 grams of DDT is recommended for the regular G. I. winter-weight 50-percent-wool underwear.

For the aqueous-emulsion method the DDT (25 percent)-Triton X–100-xylene concentrate (see Emulsions, p. 7) mentioned in connection with larvicides and residual sprays for adult insects may be used. Dilution with water to a concentration of 1.5 to 2 percent will probably be needed. This method will be most useful overseas whereever dry-cleaning solvents are not available. Ordinary laundry facilities can be used to impregnate garments in this emulsion. A portable impregnating unit for use in the field has been developed by Randall Latta, of the Bureau of Entomology and Plant Quarantine. The equipment consists of a metal stand for supporting the regular G. I. Lister bag and a small clothes wringer. Clothing can be dipped into the DDT emulsion in the bag, wrung out, and then thoroughly dried.

Individuals can prepare a small lot of emulsion in their helmets or a small bucket and dip their own underwear. If the underwear is squeezed thoroughly after dipping to distribute the emulsion throughout the cloth, as little as 1 pint will be sufficient to treat a two-piece 50-percent-wool suit of underwear. Such a treatment would require a concentration of about 4 percent of DDT in the emulsion.

Some consideration has been given to the impregnation of underwear when it is dyed, or to cloth before it is made into the finished garments, although at present these methods have not been used.

SPRAYS FOR CONTROLLING LICE AND EGGS ON BODY HAIRS

Several spray formulas have been developed and recommended for this purpose. At present the following emulsion concentrate, known by the code symbol NBIN, is standard issue: Benzyl benzoate 68, DDT 6, benzocaine (or ethyl *p*-aminobenzoate) 12, and Tween 80 14 (all percent by weight). This concentrate should be diluted in 5 volumes of water before applying. It is noninflammable, and the concentrate can be shipped for dilution overseas. Water is not only less expensive but more available in most places than alcohol, the vehicle used in formulas developed earlier in this work (discussed in Tropical Diseases Report No. 19).

This formula was developed primarily for use against head lice and crab lice. In some situations, however, it is desirable to eliminate all lice present on groups of individuals in a short period, and in such

cases lice and eggs in garments are subjected to methyl bromide fumigation or steam sterilization. Since these methods provide no residual action, it is important to destroy any lice and eggs that remain on the body.

The methods used in the application of the spray have been worked out by Army personnel, and the sprays have been applied to prisoners of war in conjunction with the methyl bromide delousing process. The prisoners are stripped, and while their clothing is being deloused they are given the spray treatment. The spray is applied, by means of a power sprayer with a paint-spray nozzle, to the pubic and anal regions, in the armpits, and on other hairy portions of the body for the control of body and crab lice. At the same time it is applied to the head for the control of head lice.

During the application the individual should hold his fingers over his eyes to prevent the spray from getting into them or onto the eyelids. Individuals should not bathe for at least 24 hours after treatment.

Not only will the treatment kill the lice and eggs present, but the residue will destroy any escaped lice for several days to a week after treatment. About 20 milliliters of spray is required to treat one individual.

Control of Head Lice

The presence of head lice can be readily revealed by examining the hair for eggs or nits. Although the presence of nits does not necessarily indicate that lice are also present, it is recommended that individuals having nits in the hair be treated unless there is time for a closer examination or it is known that all the nits have hatched or been destroyed.

The NBIN formula is highly effective against head lice. The liquid preparation is recommended as most effective and desirable for head lice, and is standard issue. However, the DDT and MYL louse powders, developed previously for the body louse, are also recommended for the control of head lice, since they are available to the troops and may be the only treatments on hand. The method of applying the various types of treatments will be discussed.

LIQUID EMULSION

The uses described below apply to the NBIN formula. The concentrate must be diluted at the rate of 1 volume to 5 volumes of water before applying.

The diluted emulsion may be applied as a spray or with the hand, depending upon the equipment available and the number of persons to be treated. From 10 to 20 milliliters is required per person, according to the amount of hair present. The material should be applied as evenly as possible and thoroughly rubbed into the hair, since the eggs must be contacted in order to be killed. It is removed when the hair is washed with soap and water.

The treatment will destroy within a few hours all lice and nits present on the head, and if the head is not washed it will prevent reinfestation for 2 weeks or longer. A treatment that does not retain its toxic effect in the hair for some time, as is the case with most head louse formulations, may permit the individual to be reinfested.

Lice, and especially eggs, may be found in the bedding, headwear, clothing, or other personal effects. The incubation period of nits found in these places may be as long as 2 weeks or more. The NBIN formula has been applied to several hundred individuals and close observations have been maintained; in no instance has one application failed to control completely the infestation.

The treatment applied every 2 weeks can be used as a prophylactic measure by persons doing delousing work or by troops mingling with infested natives.

POWDERS

The two types of louse powder, MYL and DDT, available to troops are effective against head lice, especially the DDT powder. The powder should be thoroughly dusted into the hair and rubbed in with the hands. It should also be dusted in the hat or other headwear. Since neither treatment can be depended upon to kill all the eggs, one additional treatment is suggested 1 week to 10 days later. The head should not be washed for at least 24 hours after each treatment, and if possible the powder should be allowed to remain in the hair for a longer period to aid in preventing reinfestation. Experiments on civilians indicate that one treatment with either powder will eradicate an infestation in practically all instances, and in a mass-delousing program where eradication is not the objective a second treatment is probably not necessary. However, if eradication of lice from units or from a few individuals is the objective, a second application is suggested.

Control of Crab Lice

The same treatments recommended for the control of head lice can also be used effectively against the crab louse. It is highly important that the material be applied thoroughly. Since infestations frequently occur over the entire body, especially on hairy individuals, any treatment should be applied, not only to the pubic region and to the armpits, but to the chest, back, legs, and other areas where considerable hair may be present. A few remaining lice or nits on untreated areas may serve to maintain the infestation, although it may take several weeks for the population to build up to the point where it is again detected. Under such circumstances it is generally believed that a reinfestation has occurred, whereas it is usually the result of improper treatment of the initial infestation.

POWDERS

The MYL and DDT louse powders can also be used to control crab louse infestations. The MYL formula is superior because it contains an ovicide. Generally the treatment does not destroy all the eggs, and a second treatment 7 to 10 days later is necessary to be sure of complete control. Since DDT powder is not ovicidal, it must also be applied again after 7 to 10 days.

The powder should be sprinkled on the pubic and anal regions and under the arms, and on all other areas where hair is present. In hairy individuals, as already mentioned, the best practice is to apply the powder over the entire body from neck to foot. The powder should be distributed by rubbing so that it will sift down to the base of the hair where lice and eggs are usually attached. About 10 grams of

powder will be required for the average infestation. The subject should not bathe for at least 24 hours.

The powders have been used extensively at several army camps with excellent results. A powder treatment is easily applied, does not soil clothing, and causes no discomfort, although the necessity of a second treatment is a disadvantage.

LIQUID PREPARATIONS

Formula NBIN, discussed in connection with the control of body and head lice, is also recommended for use against crab lice. This treatment should also be applied to all hairy portions of the body and allowed to remain for at least 24 hours. The material may be applied with a sponge or piece of cotton, by hand, or by means of a sprayer. About 30 ml. is usually sufficient, but heavily infested hairy individuals may require as much as 50 to 75 ml. One thorough treatment will control an infestation, but will not eliminate the lice unless all eggs are contacted. If a second treatment is necessary, it should be given about 10 days after the first.

Control of Scabies

As a result of studies at this laboratory and through the cooperation of several Medical and Sanitary Corps officers in the Army, a great deal of information has been obtained on various scabies treatments.

The NBIN formula recommended for louse control is very effective as a scabicide. Benzyl benzoate has been used extensively for this purpose in England and elsewhere, but when used in the NBIN formula it has been found to be more effective. This increased effectiveness is indicated to be due to the benzocaine and possibly to the other ingredients. The benzocaine was added primarily as an ovicide, but it is also a local anesthetic which relieves the itching that usually accompanies the presence of lice and the scabies mite.

The NBIN formula has practically no odor and does not leave an undesirable residue on the body. It has shown no tendency to irritate the more tender areas of the skin. When a case of scabies is to be treated, the required amount of the concentrate should be diluted at the rate of 1 part to 5 parts of water, as recommended for louse control. The diluted material may be applied as a spray or by hand with a sponge. The entire body except the head must be treated, with particular attention to the places where lesions are apparent. About 60 to 75 ml. of the diluted emulsion is usually required for one treatment. The patient should be instructed not to bathe for 24 hours. One thorough application has been found to eliminate an infection of scabies, but if a second treatment is required, it should be made about 1 week later.

VIII. Insect Repellents

General Discussion

Laboratory and field tests have shown that a repellent may vary greatly in effectiveness against different insects, and that materials capable of prolonged protection against some species may fail completely to repel others (see Chemistry of Repellents and Miticides,

p: 10). Of the materials first recommended as repellents (dimethyl phthalate, Rutgers 612, and Indalone) and later issued for protection of troops against biting insects, this variation in effectiveness was one of the main objections to all three. Each was particularly effective against certain insects, and a mixture of the three was found to be effective against a wider range of species than any of the individual repellents. The resultant repellent, known as a 6–2–2 mix, which is now standard issue, contains, by volume, 60 percent of dimethyl phthalate, 20 percent of Rutgers 612, and 20 percent of Indalone. A 1–1–1 mix appeared equally effective, and this has been issued when the relative availability of the three repellents made it necessary to modify the mixture.

A large number of materials, which were produced through the coordinated effort of several university groups working under funds allotted by the Office of Scientific Research and Development, have recently been evaluated as mosquito repellents at the Orlando laboratory. Some of them show considerable promise as practical repellents.

Repellents for Mosquitoes

APPLICATION TO SKIN

Liquids

All the repellents are used in the same manner. About 12 drops should be shaken into one hand, the hands rubbed together, and the repellent applied in a thin layer to the face, neck, ears, hands, and wrists. The repellent must be uniformly distributed over the area to be protected, as the insects will bite places inadequately treated or where the material has been rubbed off. Care should be taken not to apply the material too liberally on the forehead, as it stings if it gets in the eyes.

The recommended repellents will give protection for 1 to 5 hours, depending on the rate of application, the species of insect, the humidity, the amount of perspiration, and the rubbing of treated areas. Studies at Orlando have shown considerable seasonal variation in the effectiveness of repellents. Since the shortest protection times are obtained through the summer, the protection time appears to be directly associated with the rate of perspiration. Laboratory studies at the Naval Research Center, Bethesda, Md., have shown a definite relationship between rate of sweating and repellent-protection time. There is also an unexplained variation in effectiveness among individual users.

Since all the liquid repellents now in use are solvents of paints, varnishes, and many of the plastics, such as watch crystals and some types of synthetic cloth, they should be used with caution where these materials are part of the uniform or equipment.

Creams

In the laboratory it has been found that, at equal dosages, protection time can be approximately doubled, as compared with the liquid, by incorporating the repellent in a suitable powder-base cream. Tests conducted by the armed services to determine the acceptability of such creams under service conditions indicated that they were not cosmetically acceptable.

APPLICATION TO CLOTHING

Attempts have been made to develop clothing impervious to mosquito bites. Several fabrics furnished by the Office of the Quartermaster and tested at Orlando gave highly satisfactory results, but until resistant clothing is standard issue much relief and freedom from insect-borne disease can be obtained by treating the clothing with a repellent. Although all repellents are effective for only a few hours on the skin, they will repel insects for a number of days when applied to clothing. It has been found that head and bed nets of much wider mesh than that ordinarily used can be employed if treated

FIGURE 23.—Open-mesh and conventional type of head nets. (Photo by AAFCTR, Orlando, Fla.)

with repellents. This will increase the comfort of the individual and provide better vision. Figure 23 shows a wide-mesh head net and the type usually issued. Although the application of repellents to clothing will not completely protect the untreated skin, there is evidence that the number of bites received is reduced when the clothing is treated. The following methods of application are suggested:

Hand application

Under field conditions where no equipment is available, fair protection may be obtained from hand application. About 12 drops of the repellent should be shaken into one hand, and the hands rubbed

together and then rubbed lightly and as evenly as possible on socks, shirts, or trousers (fig. 24). The procedure should be repeated until reasonably good coverage is obtained on the areas where most bites occur.

Sprayers

Ordinary hand sprayers can be used to apply repellent materials to clothing (fig. 25), but for large groups decontamination sprayers or paint-spray guns may be required. A sprayer that delivers a fine but wet spray is better than one that delivers a fog or small droplets.

FIGURE 24.—Treatment of clothing by hand with repellents for protection from mosquitoes.

A fog spray floats away, and will cause irritation to the eyes and lungs. About 4 ounces of repellent per suit should be used, with particular attention to areas where most bites occur, such as the shoulders, rump, and knees. If more than 4 ounces is applied, the clothing may be slightly oily and have a tendency to pick up dirt. A wet spray can be applied to clothing on the body, but care should be taken to protect the eyes. With the fog type of spray, loss of material can be largely avoided by spraying clothing turned inside out and buttoned. One man can hold shut the opening of the sleeves and neck of the shirt and the bottom of the legs of the trousers, while another sprays into these bag-shaped garments. The use of an atomized sprayer for application of the repellent is shown in figure 26.

Impregnation of clothing

Volatile solvent.—If a suitable volatile solvent is available, clothing may be dipped in a 20-percent solution of any of the recommended repellents and then hung up until the solvent has evaporated. Rutgers 612 and Indalone are soluble in light petroleum solvents, such as Stoddard solvent, but dimethyl phthalate is not. However, it is probable that for some time to come the only repellent available in bulk for clothing treatment will be dimethyl phthalate. It is soluble in ethyl alcohol, acetone, and acetylene tetrachloride, but the first two solvents are probably not available for this use, and the third is too toxic to be used except by trained personnel in Chemical Warfare Service

Figure 25.—Ordinary hand sprayer being used to treat clothing for protection against mites and mosquitoes.

impregnating plants. These factors will probably greatly limit this method of impregnation.

Emulsions.—The ease of treating uniforms by dipping and the nonavailability of solvents in war areas stimulated investigation at Orlando on the development of aqueous emulsions for this purpose. It was believed necessary to have a 15- to 20-percent emulsion in order to deposit sufficient repellent in the uniform to give protection against mosquitoes. Soap and a large number of other emulsifying agents were investigated, but most of them were discarded because they required heat for preparation, were not readily miscible with cold dimethyl phthalate, formed emulsions that broke or creamed too rapidly, were not available in large quantities, or were irritating to the skin. However, several were found that were very satisfactory.

To use dimethyl phthalate with added emulsifier, the materials are simply poured into tap water while stirring. After the dry clothing has been dipped and wrung out, the amount of repellent retained will be about 6 to 8 ounces, depending on the kind and size of the uniform. Somewhat more repellent is needed for impregnation than for spraying, since with impregnation methods some repellent is deposited in seams, cuffs, or at other points which would not be reached by a spray.

FIGURE 26.—Use of atomized sprayer for treating garments with repellents for protection against mites or mosquitoes. (Photo by AAFCTR, Orlando, Fla.)

Clothing so impregnated may be expected to give protection from mosquito bites for 1 week unless the repellent is washed out by rain, wading, or laundering.

If no other emulsifier is available, dimethyl phthalate can be emulsified with laundry soap as described in Part IX.

CONDITIONS UNDER WHICH REPELLENTS SHOULD BE USED

The value of repellents in protection from annoyance or diseases transmitted by mosquitoes and biting flies depends to a great extent on the situation under which troops are living or working and on

what other means of protection may be feasible. Repellents and treated clothing are frequently the only means of protecting troops on the march or in forward combat positions. Repellents should be used especially during the period that the disease vector is most active. In the case of anopheline mosquitoes this would be during the night, particularly at dusk and dawn. In temporary cantonment areas, troops on maneuvers, at work, on guard duty, or when otherwise exposed outdoors, should use repellents in the manner described, but under these conditions they may be able to rely largely on other means of protection, such as screens, bed nets, head nets, gloves, aerosols, spray residues, and larvicides. In permanent camps repellents may be useful, but emphasis should be given to control or elimination of the insect vector.

Repellents for Other Insects

As in the case of mosquitoes, DDT may be used to eliminate infestations of some of the other important vectors through the application of sprays, but in many instances repellents may have to be relied upon until other control measures can be initiated or in situations where other methods of control are not feasible.

Any of the repellents now issued—dimethyl phthalate, Rutgers 612, Indalone, the 6–2–2 mixture, or the 1–1–1 mixture—may be used for protection against a number of other insect pests.

The repellent should be applied to the exposed skin. Against pests which bite through or crawl upon the clothing much better protection can be obtained by treating the clothing in the manner described for mosquito protection. This is particularly important when one is going into areas containing land leaches or infected ticks or fleas. Treated clothing also reduces the number of bites received on exposed skin from mosquitoes and other insects. Effectiveness of the repellents against mites is discussed under Part IX.

IX. Protective Measures Against Mites

General Discussion

Mites (chiggers, red bugs) of the genus *Trombicula* and related genera are of added importance during wartime through the transmission of mite typhus (also called scrub typhus or Tsutsugamushi disease). Mites are distributed in tropical regions throughout the world. Considerable annoyance and irritation are caused by their attachment to the skin, but they were of greatest concern to the armed forces as vectors of this disease. Mite typhus was important in the Pacific and China-Burma-India theaters.

Mite investigations at Orlando were initiated in 1942, and dimethyl phthalate, Rutgers 612, and Indalone (see Chemistry of Repellents and Miticides, p. 10, and Part VIII) were found to be highly effective when applied to all openings of the clothing. Of the three repellents, dimethyl phthalate was the most effective and desirable. Studies on this problem were temporarily suspended following the recommendation that these repellents be used to prevent mite attachment.

Investigators in Australia later noted that dimethyl phthalate and other repellents acted primarily as killing agents for mites rather

than as repellents. These workers also found dibutyl phthalate to be superior to dimethyl phthalate from the standpoint of resistance to removal from clothing through exposure to water, rain, wading, or laundering.

Because of the military importance of these mites, the Typhus Commission initiated investigations principally to develop effective miticides that were resistant to removal from clothing through rinsing in water or laundering, and to develop practical methods of applying miticides under field conditions.

Mite-control investigations were again undertaken at the Orlando laboratory in the spring of 1944, in cooperation with the Typhus Commission. A large number of new materials were evaluated under laboratory and field conditions. Some of these showed considerable promise, and one, benzyl benzoate, has recently been recommended.

Comparative studies of dimethyl phthalate and dibutyl phthalate have been made by various investigators in different parts of the world. Although dimethyl phthalate as a fresh treatment is highly effective and more rapid in its miticidal action, dibutyl phthalate is generally considered to be more persistent when treated clothing is laundered. Studies by the Orlando staff have confirmed the findings of other workers regarding the relative persistence of these two materials, but under conditions of heavy mite populations dibutyl phthalate was found to allow a few attachments even when applied as a fresh treatment. When the clothing was washed,[9] results were very erratic. In some instances the effectiveness persisted after as many as three launderings, whereas in others a large number of attachments were obtained after one laundering.

Under the same conditions benzyl benzoate has consistently provided almost complete protection after two launderings and a high degree of protection after three launderings. Similar results have recently been reported by the Typhus Commission. Benzyl benzoate has been in use in England for a number of years, and is the principal scabicidal ingredient in the NBIN formula recommended in Part VII of this report. The Food and Drug Administration has approved the use of benzyl benzoate as a skin treatment for the control of scabies. In view of its acceptability from the standpoint of toxicity, and its effective and persistent miticidal qualities, it is considered a very desirable material for use in mite control. Furthermore, it does not stain clothing, and possesses very little odor.

Owing to the effectiveness of benzyl benzoate every effort is being made by the Office of the Quartermaster to provide sufficient quantities of this miticide. Supplies are at present limited, however, and plans are being made to supply a mixture of equal parts of benzyl benzoate and dibutyl phthalate. Tests with this mixture show it to be highly effective, and almost equal in effectiveness to benzyl benzoate alone.

Conditions Under Which Miticides Should Be Used

Individuals exposed to mites (chiggers) are not aware of their presence for several hours after exposure, and in some cases no irrita-

[9] Laundering consisted in placing a treated uniform in water containing 0.76 percent of G. I. soap at 120° F. for 10 minutes in a domestic electric washing machine and rinsing twice in cold water, for 5 minutes each time.

tion is produced although the subjects may contract the mite disease. By the time irritation is noted the damage has been done, and even though the mites are destroyed the irritation may persist for several days to a week or more, and infection with the mite disease or secondary infections from scratching or rubbing may result.

It is therefore important that mite attack be anticipated, and troops in infested territory should be provided with mite treatments prior to exposure.

Methods of Applying Miticides

Four methods of applying miticides are suggested. The first consists in the application of a repellent barrier to all openings of the clothing, the second in smearing the miticide over the uniform by hand, the third in the use of sprayers, and the fourth in dipping the garments.

BARRIER METHOD

Bottles of insect repellent may be employed by the individual. The repellent should be applied thoroughly and liberally as follows: Draw the mouth of the bottle along the cloth, applying a thin layer ½ inch wide along all openings of the uniform—inside the neck, fly, and cuffs of the shirt; waist, fly, and cuffs of trousers—in the socks above the shoes, and at all edges of the leggings. Figure 27 demonstrates the barrier method of treatment for mites. Clothing may be treated several days before it is worn, and one application remains effective for several days unless subjected to washing, excessive rain, or wading.

HAND APPLICATION

The material may be applied very simply by pouring a small amount into one hand, rubbing the hands together, and smearing it over the uniform. One or two ounces per uniform applied carefully in this manner will give good protection. This method has been used extensively in Australia.

SPRAYERS

The spray procedure described for the application of repellents to clothing for protection from mosquitoes (see Sprayers, p. 61) can be followed with some modification. The miticide should be well distributed over the clothing with a wet spray if possible. Special attention should be given to the neck, fly, and cuffs of the shirt; and waist, fly, and cuffs of the trousers. The socks and leggings should also be treated. About 4 to 5 ounces of repellent is suggested for one uniform.

IMPREGNATION METHOD

Miticides may be applied by dipping the entire uniform. Ethyl alcohol, acetone, or acetylene tetrachloride are suitable solvents for dimethyl phthalate, dibutyl phthalate, and benzyl benzoate. Nonavailability of alcohol and acetone, however, preclude their use for this purpose in the field, and acetylene tetrachloride is too toxic to be used except by trained personnel in Chemical Warfare Service impregnation plants (see Impregnation of Garments, p. 54).

Lack of available solvents caused Capt. R. C. Blushland, of the Typhus Commission, to use an emulsion prepared with G. I. soap

for treatment of uniforms in the South Pacific area. The procedure described below is quoted from a letter from him dated March 23, 1944, and can be used for dimethyl phthalate, dibutyl phthalate, or benzyl benzoate.

The method of impregnating clothing is very simple and the treatment of 100 uniforms can be described as follows:

Materials required.—Dimethyl phthalate 7.5 qt., G. I. soap 6 lb. (7½ 14-oz. bars), water 35 gal.

Treatment.—Cut soap into small pieces and boil in 10 gallons of water to

FIGURE 27.—Insect repellents being used by individual for protection from mites.

dissolve. Then add 25 gallons of cold water with stirring. Pour 5 gallons of this soap solution in a G. I. can and add the miticide slowly while stirring vigorously with an egg whip. Then add the remaining 30 gallons of soap solution with stirring to make the finished emulsion. One man should keep stirring this emulsion slowly while clothing is being dipped to assure uniform treatment.

Put socks in trousers pockets. Immerse clothing in emulsion, remove and wring out (over another can to save excess liquid), then hang uniform on clothesline. The clothing is ready to be worn when dry.

The time and labor involved in preparing soap emulsions has focused attention on the desirability of using a miticide containing an emulsi-

fier. It was found that a satisfactory mite treatment was the dimethyl phthalate-emulsifier combination originally developed at Orlando as a clothing treatment for protection against mosquitoes (see Chemistry of Repellents and Miticides, p. 10, and Emulsions, p. 7). This material is now being packaged in 1-gallon containers and shipped to the scrub-typhus area for clothing treatment. Benzyl benzoate and dibutyl phthalate can also be satisfactorily packaged with included emulsifier. Such combinations make good emulsions by shaking vigorously with two to three times their volume of water until a creamy emulsion is obtained and then diluting with water, while stirring, to the desired repellent concentration (usually 5 percent). Some of the emulsifiers may be used with sea water also as indicated in Chemistry of Repellents and Miticides.

Control of Mites in Breeding Areas

Under certain conditions it is desirable to treat mite-infested areas to control the insects in their breeding places. This would be especially desirable around camps, bivouac, and other restricted areas. Sulfur has been used in the past, applied at the rate of 50 pounds per acre.

Studies have recently been initiated at this laboratory in efforts to develop effective mite treatments for area control. A number of materials have ben tested on small plots. At present the studies have not advanced sufficiently to recommend materials for this purpose. Of the several promising treatments benzene hexachloride is indicated to be most effective.

X. The Toxicity of DDT, Solvents, Emulsifiers, Activators, and Other Adjuvants Mentioned in This Report

By Hebbert O. Calvery,[10] *Division of Pharmacology, Food and Drug Administration*, and Paul A. Neal, *Laboratory of Industrial Hygiene, National Institute of Health, Federal Security Agency*

Introduction

In the latter part of 1941, before our entry into the war, owing to the foresight of members of the Office of the Surgeon General of the Army, particularly Gen. J. S. Simmons and Col. W. S. Stone, concerning the possible hazard involved in the extensive and repeated use of insect repellents and lousicides, the Division of Pharmacology of the Food and Drug Administration was asked to investigate the toxicity of repellents and lousicides being considered for adoption by the Army. Early in 1942 M. I. Smith, of the Public Health Service, and a little later, when the hazard of inhalation was recognized, Paul A. Neal, director of the Laboratory of Industrial Hygiene of the National Institute of Health, was asked to join in the work. The following publications relating to this work have now appeared, most of them dealing with DDT:

Calvery. 1945. Food Packer 26 (5): 61–62.
Draize *et al.* 1944. Jour. Pharmacol. and Expt. Ther. 82: 159–166.
——— 1944. Chem. and Engin. News 22: 1503–1504.

[10] Died September 23, 1945.

Lillie and Smith. 1944. U. S. Pub. Health Serv. Rpts. 59: 979–984.
Neal *et al.* 1944. U. S. Pub. Health Serv. Rpts., Sup. 177, 32 pp.
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Woodward *et al.* 1944. Jour. Pharmacol. and Expt. Ther. 82: 152–158.

DDT (1-Trichloro-2,2-bis(*p*-chlorophenyl)ethane)

Although some toxicity studies of DDT had been carried out in Switzerland, the results were unavailable when the first sample, a 5-percent powder in an inert diluent, was received by the Division of Pharmacology in March 1943. It was soon demonstrated that DDT in powdered form presented no hazard as a skin irritant, and neither could absorption be detected in this form. From organic solvents and oil solutions it is absorbed through the skin and may present a hazard. It causes toxic manifestations by any route of administration. Its toxicity has been tested on at least 12 species of mammals, and for all of these it has been found toxic, the manifestations being similar in all species. Everyone seems to agree that it is a nervous-system poison primarily of central origin, but can cause damage to other tissues and organs as well. There is a wide range of tolerance to DDT, not only among species but among individuals of the same species, following the usual routes of administration. Since intravenous administration of certain types of emulsions gives sharp dosage-mortality relationships, this probably means that DDT is irregularly absorbed when otherwise administered, and as a result makes the establishment of a safe level very difficult. However, the information available from all sources indicates that the proposed uses of DDT present little, if any, hazard if the recommended precautions are followed. The Committee on Medical Research has assembled a series of methods useful in the quantitative estimation of DDT.

Hydrocarbon Solvents

The hydrocarbon solvents mentioned in this report are kerosene, fuel oil, tetrahydronaphthalene, xylene, Heavy Solvent, PD 544–C, Velsicol AR–50, K–327, S/V Culicide Oil, Velsicol NR–70, APS–202, Hi-Flash Solvent, and Solvesso No. 3. Some of these, to the best of our knowledge, have not been investigated toxicologically, but some are being studied. Others have been thoroughly investigated. It is recognized that all of them introduce the hazard of dermatitis, as well as possible toxicity, from inhalation and skin absorption. Therefore, where recommended precautions for the handling of these materials are issued, they should be followed; this is particularly true of those that have not been studied, namely, PD 544–C, K–327, S/V Culicide Oil, APS–202, and Solvesso No. 3.

Nonhydrocarbon Solvents

The nonhydrocarbon solvents mentioned in this report are cyclohexanone, *o*-dichlorobenzene, and isophorone, all of which have been

investigated toxicologically. They are considered safe under the conditions of use if the recommended precautions are followed. Chlorinated hydrocarbons, such as carbon tetrachloride and tetrachloroethylene, should not be used because of the hazard involved.

Emulsifiers (Surface-Active Agents)

The following emulsifiers are mentioned in the report:

Triton X–100.
Span 20.
Tween 20.
Span 60.
Tween 80.
Alkanol B; SA; WXN.
Aresklene 400.
Emulphor ELA.
Wetsit Concentrated.
Duponol C.
Stearate 61–C–2280.
Polymerized glycol monostearate.
Polymerized glycol monolaurate.

The studies of emulsifiers have been confined primarily to their effects on the skin, since there is no hazard from ingestion and little from skin absorption and inhalation. They have also been studied to some extent from the standpoint of their relationship to increased absorption of DDT. All of those studied present little or no hazard under the conditions of use recommended, and have been approved for that purpose so far as the toxicology is concerned. Duponol C is most irritating and Triton X–100 next, whereas the others are all in the same category and in the concentrations used in the finished preparation have very little irritating effects. Some of the concentrates are rather irritating; therefore, skin contact with any of the concentrates should be avoided or carefully limited. Most, if not all, of them have been studied in the final preparation as recommended for use. Alkanol B, SA, WXN; Aresklene 400; Emulphor ELA; and Wetsit Concentrated have not been studied for their toxicological effects, and because of their widely varying properties, we are unable to predict their effects.

Repellents

The repellents—dimethyl phthalate, Rutgers 612, Indalone, a mixture of these three, and benzyl benzoate—have all been studied toxicologically and found to be safe for the recommended uses. Indalone and benzyl benzoate must have a high degree of purity, since there are contaminants which, if present, may be deleterious. These contaminants are not present in the product being used at the present time.

Miscellaneous

Other substances mentioned in the report having one or another function in the preparation as used are benzocaine, N-isobutylundecylenamide, 2,4-dinitroanisole, Phenol S, and pyrethrum. All these have been studied and are considered safe in the concentrations in which they are used in the recommended preparation.

Discussion

It should be clearly kept in mind that most of the substances under consideration are poisonous. If they were not, they would probably be useless against the insects for which they are recommended. Therefore, the recommendations for the proper use of these substances should be followed. Careless, unnecessary exposure and misuse is fraught with hazard.

It should be further kept in mind that probably no chemical is safe for every individual, even when properly used. Therefore, occasional complaints will arise, some justified, but the benefits derived must be weighed against the hazards involved and justification for the continued use of the preparation determined. It is our opinion that at present the justification for the use of the preparations recommended in this bulletin far outweighs any hazard involved.

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ORGANIZATION OF ORLANDO, FLA., LABORATORY

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RESEARCH SUBJECTS

A total of 60 men acting as research subjects.

1/ Assigned from Army Air Forces Committee on Aerial Dispersal of Insecticides located at Army Air Forces Center, Orlando, Fla.
2/ Assigned through courtesy of the Office of the Surgeon General, U. S. Army.
3/ On military furlough, U. S. Navy.
4/ On military furlough, U. S. Army.
5/ On military furlough, U. S. Marines.